THE

ONTARIO WATER RESOURCES

COMMISSION

BASIC COURSE

FOR

WATER WORKS OPERATORS

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BASIC WATER WORKS COURSE

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PUBLIC HEALTH ASPECTS OF WATER TREATMENT

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INTRODUCTION

The title of this lecture is Public Health Aspects of Water Treatment and consequently it might be wise at the outset to recognize what constitutes public health. The World Health Organization defines health as "a state of complete physical, mental, and social well being and not merely the absence of disease or infirmity". The second definition which has been presented reads in part "public health is the science and the art of preventing disease, prolonging life and permanent physical health and efficiency through organized community efforts of sanitation and environment............".

The reduction of typhoid fever and other related diseases of the environment has been attained consistently over many years, although some examples will be given at a later point to indicate that typhoid has not been completely eliminated. However, statistics on the occurrence of typhoid fever almost have vanished from the records. Knowledge and the wide application of measures for the purification of water, the control of stream sanitation, and the pasteurization of milk leave little reason for failure to use them to the full. The greatest danger today results not from the suitability of these protective measures but rather from a false sence of security brought about by the absence of such outbreaks and the carelessness of the use of these methods. There is a need to continually impress all

in charge of sanitary programmes with the knowledge that these dangers do exist, and any break in the protective armour can quickly lead to disaster.

The need for water supplies is now receiving more recognition than at any previous time. This can be attributed to a public awareness that unless this commodity is available public health suffers, communities cannot develop, and gradual deterioration must be expected. The trend to urbanization in this country adds emphasis to this need.

The emphasis on water supply has for the most part shifted from safety against disease to quantity and quality for all uses. A supply that is not adequate at all times is defective in the eyes of the consumer. Similarly, water that is not free from odour, colour, and turbidity or has an objectionable taste or other physical or chemical constituent does not fit into a good public health environment. Thus, the major emphasis has now switched from the original requirement of the safety of the supply to these other factors.

There is an abundant supply of water in Ontario, but distribution of the water creates problems in many places. Pollution in any one of many forms can destroy the available water to a community. The cost of bringing water long distances is high, but in spite of this, water is essential above all else and as such can well be considered as a priceless commodity. As this country grows more and more emphasis must be given to conservation and distribution of water supplies.

THE IMPORTANCE OF WATER SUPPLIES

Water is one of man's most vital requirements. No living thing, whether it swims, crawls, flies or walks up-right can live without water. Water is essential to his heart beat and his lungs; it cleanses both inwardly and outwardly; it makes possible his nourishment as a solvent and carrier of food within his body. It is so important that man himself is composed of more than 80 per cent water.

The importance of water was realized by the ancient people who believed that there were only four elements--air, earth, fire and water.

Water is also a major public servant inasmuch as it removes wastes from homes, it washes the streets, waters gardens and lawns, and provides protection against fire. Further, it makes agriculture possible and the production of food stuff, both plant and animal.

Other aspects of the importance of water are its use as a source of energy, as a means of transportation, its use in industry, its wide use in industrial processing and as a source of recreation.

Considering the significance of water it is important therefore that all public health aspects be given consideration with respect to water protection and treatment. In order to be wholesome water must be:

1. Uncontaminated and of a quality that will not cause disease to consumers.

2. Free from excessive amounts of mineral and organic matter.

3. Free from any material of a poisonous nature.

PUBLIC HEALTH REQUIREMENTS

The major requirements of any water works from a public health standpoint can be listed as follows:

1. The quality of the water must meet the standards established by the public health and water works authorities.

2. The personnel should be aware of existing and potential sources of contamination that endanger their water works and they should have the knowledge and facilities available to meet the danger of pollution.

3. Responsible trained personnel should be in charge of water treatment plants.

4. The water treatment plant should be properly designed.

FIRST REQUIREMENT - MAINTENANCE OF ESTABLISHED STANDARDS

The major public health requirement of water treatment is that the quality of the product must meet certain standards. These were initially established in 1914 by the United States Public Health Service. Over the years these have been amended and revised in co-operation with various associations--principally, the American Water Works Association; the latest revision being in 1962. The revisions which have taken place through the years reflect the associated progress in the water treatment field and the revisions have been associated with three major requirements: viz,

1. Bacteriological
2. Physical
3. Chemical

At the present time the OWRC is preparing a publication entitled Drinking Water Objectives and it is expected that this will be issued during the current year. Until such a time as this publication becomes available, the Unites States Public Health Service 1962 Drinking Water Standards should be followed.

SAMPLING OF WATER -- BACTERIOLOGICAL SAMPLES

It is essential that regular samples be submitted for bacteriological analyses if one is to judge the quality of the water properly. One raw water sample is required per month from each surface water supply. This programme is designed to monitor the bacteriological quality and safety of the raw water. Secondly, a routine bacteriological sampling programme is required on all distribution systems. For populations up to 2000, two bacteriological samples should be submitted each month and for populations from 2000 to 100,000, one sample per 1000 population should be submitted.

It is emphasized that to ensure reliable results, samples should arrive at the laboratory within 24 hours of sampling or be refrigerated if a delay is unavoidable. Further, samples from the distribution system should be taken only after the water has been flowing for not less than two minutes. The samples should be collected directly into sterile bottles, not be means of a dipper or other container.

Chemical Samples

Each well supply should be sampled once a year. The chemical sample is submitted to the Commission Laboratory with a request for routine chemical analyses plus a fluoride determination.

A surface water source of supply should be sampled on a monthly basis, with a raw water sample being submitted from each source of supply to the Commission Laboratory with a request for routine chemical analyses plus colour and turbidity. If and when consistent results are obtained a reduced programme of submitting samples on a quarter annual basis may be recommended.

Fluoride Samples

If fluoridation of the supply is practised, two samples from the distribution system should be submitted per month to the Commission Laboratory. This programme is designed to check the routine fluoride analyses performed at the water works.

The bacteriological standards were the most important at the time that the U.S.P.H.S. standards were established in 1914. At that time, danger from bacterial contamination was a major problem. The provision of filtration and then chlorination with many variations in this treatment has minimized the enteric water-borne infections such as typhoid fever, paratyphoid fever, and dysentry. The fact that communities have been relatively free of attack for generations does not limit the possibility of a water-borne epidemic. Periodically, over the past few years epidemics have been reported

which can be related to contaminated water supplies. For example, in November and December of 1959, the community of Keene, New Hampshire, experienced a typhoid epidemic. The source of the infection was finally traced, after considerable investigation, to the Keene water supply. This community's water supply consisted of an unspoiled mountain watershed and a good slow sand filter treatment plant. All of these factors combined with careful water distribution practices would indicate that the consumer would be receiving a safe quality water. However, over night the water system turned into a distributor of the organisms of deadly typhoid fever.

A curious combination of circumstances lead to the typhoid infection. A wood cutter, working in the watershed area without authorization, was discovered to be a typhoid carrier. His waste had been washed into the city's water during unusual flooding in October.

The epidemic at its height affected 19 people and was known to have taken the life of at least one. The city officials were suddenly made aware that the city was in the business of producing a product--the safety of which they had a legal and moral responsibility to guarantee. The Council was faced with the alternatives either of paying $67,000 in settlement of the claims or allowing these claimants to sue the city. One attorney estimated that the costs of going to court could have risen as high as one-half million dollars.

It is noted that for at least a decade prior to the epidemic local health and water authorities, the city's consulting engineer, and the state Board of Health, had all recommended the installation and continuous operation of chlorination facilities. However, the City Council repeatedly denied the requests. The result was that Keene has now paid several times the cost of installation and operation of chlorination facilities and at the same time not have the value of those facilities. Further, the Water Department suffered a considerable loss of public face.

This example has been included here to point out that there will always be a need for continued responsible supervision at any water treatment plant to ensure that the quality of the water will not be affected and that there will be no return to the water-borne epidemics of another era. The first public health requirement in water works treatment continues to be responsible supervision to assure that proper standards are reached to maintain the quality of the water.

TREATMENT REQUIRED TO MAINTAIN STANDARDS

The main treatment that assures proper bacteriological quality is chlorination, although filtration does play a definite role in this respect. Ontario has relied on marginal chlorination through the years and until recently has required that a chlorine residual of not less than 0.2 p.p.m. be maintained in the water after 15 minutes contact between the chlorine and the water.

During 1962, the chlorination policy of the OWRC was reviewed and subsequently revised. The new policy now requires residuals of up to 0.5 p.p.m. chlorine dependent on the individual circumstances. This chlorination policy will be reviewed in detail in a subsequent lecture.

No objection has been raised to the use of super-chlorination or break-point chlorination, wherever an operator of a plant deems it desirable for better operation of his plant.

Many of the chemical constituents that cause unsatisfactory quality are more important in evaluating the quality of ground water from wells than surface waters. Iron, chloride, sulphate and hydrogen sulphide contents often make ground waters objectionable from taste, odour and other standpoints. In some instances, the contents are so high that the water becomes unusable. On the other hand, chemical pollution by industrial wastes

of surface waters has become a greater problem in recent years necessitating that practically all water works systems in industrial areas have to have taste control methods available.

SECOND REQUIREMENT - KNOWLEDGE OF POLLUTION ENDANGERING PLANT

The second requirement has become more important in recent years as communities become increasingly industrialized and natural water sources have become more vulnerable to pollution from domestic and industrial wastes. The job of keeping our drinking water safe has become an increasingly vital and difficult task. It is recognized that the war against pollution is in progress but the battle is only beginning. Municipalities still discharge untreated or partially treated sewage into the streams, and industry aggravates the problem by dumping an ever changing variety of chemical contaminants.

The water works, and particularly those in the larger and more populated areas, are now confronted with problems that were not present a few years ago. If the water treatment works are to function properly it is essential from a public health standpoint, that their personnel know the sources of contamination that are or may become a danger to the quality of the water in their plant. The amount of close supervision required in operating a plant is materially increased in those areas that known sources of contamination are present.

It should not be assumed that all sewage treatment plants are properly designed, have adequate capacity and are capable of turning out a good effluent on all occasions. Therefore, it is essential that the location of the points of sanitary discharge in the area be known and the efficiency of the sewage treatments determined.

Do not take sewage plant effluents for granted. Find out by frequent raw water sampling if they are a danger to the water works and then, if necessary, take every precaution to combat such contamination, until it is eliminated by the provision of better sewage treatment facilities.

Sources of industrial waste pollution should also be known to the personnel of water works plants. An ever-changing variety of chemical and other waste discharges are reaching water works plants. As a result, it is rare indeed to find a water works in an industrial area which does not have some type of taste control treatment available. Radiological, anionic detergent, pesticide, phenolic and other organic wastes from industrial sources and from land run-off have brought new and perplexing problems that are often difficult to solve. Industries are sometimes located extremely close to water works intakes thereby increasing the need for careful supervision in the water works plant.

In recent years there have appeared in the press and elsewhere statements relative to the increasing hazards to the quality of water supplies from sanitary, chemical and other contaminants that reach and may pass through water works plants. In particular, the number of new enteric viruses that have been discovered to be present in human wastes and against which the usual chlorination treatment has little effect, has caused some concern. It is recognized that modern water treatment methods can and do prevent contaminated water from affecting a community's health in almost every instance. However, there is a limit to even the efficiency of our purification plants if the contaminants are to continue in an ever-changing variety. It is true that conditions are probably not as bad as pictured, as there has been no evidence of any major recession to the water-borne epidemics of a few years ago. It would be folly not to follow with every interest, the work that is being carried out in this field and be ready to make changes in water treatment, particularly in the field of chlorination.

A second public health requirement, therefore, is that the personnel in the water works plant should know the sources of contamination that endanger their operation and should have every facility available to counteract such pollution if it ever reaches the plant.

THIRD REQUIREMENT - TRAINED WATER WORKS PERSONNEL

Another public health requirement is that the operation of the water supply system should be under the supervision of responsible personnel whose qualifications are assured by a recognized authority. While this is desirable, it must be agreed that this standard cannot always be secured, particularly in the smaller plants which have only chlorination treatment or none at all. The person in charge of treatment in a medium sized or large filtration plant should be one that has some knowledge in the fields of chemistry and bacteriology of water if the finished product is to be turned out to the best possible standard. In many plants there is a chemist to supervise the treatment and an engineer to take charge of mechanical details to assure proper operation.

In smaller plants the need for a person with a detailed knowledge of chemistry and bacteriology is not as essential but some knowledge in those subjects is of value in any plant to enable the operator to turn out a safe water with the facilities that he has available. That is one of the reasons for training courses such as the one being given at this time. The purpose of this course and others like it is to acquaint operators, particularly in smaller and medium sized plants, with methods and treatments that can be used to assure a safe water at all times, as it has been recognized that public health requirements demand responsible, trained, personnel in water works plants regardless of their size.

A well trained operator is definitely of value if a water works plant is to function properly. However, any conclusion that all uncertified operators are unqualified to operate a treatment plant is unjustified. Many operators through adequate initial instruction from their fellow operators and by studying the literature, become well qualified to operate their own or similar plants. It is, of course, an advantage if the instruction that he has acquired in this way can be supplemented by schools of training to enable him to have a better knowledge of the field of water plant operation.

The water treatment plant operator is vital to the health of the community as producer of safe, palatable water, and to the safety of the community as the provider of adequate water to fight fires. It is essential, therefore, that he have every opportunity to provide the personal supervision that is required in this field.

It is recognized that a water works operator is and will continue to be the main cog in the provision of a satisfactory water from a public health standpoint. It is essential, therefore, that he have assistance and training to assist him to a better understanding of the complex nature of water treatment. As the industrial era develops more fully, there is now a more urgent demand for more research in individual water utilities. Also, there should be an appreciation of the importance of the work of operators so that in the future better salaries will help to ensure more interest in the field and a desire on the part of operators for more knowledge to operate their plants.

FOURTH REQUIREMENT - PROPERLY DESIGNED PLANTS

Another public health requirement is that the water works plant should be so designed that the operator can turn out a satisfactory quality water at all times. It is recognized that not all water works plants have been properly designed. Some have been built to meet the economy of the community rather than to meet general recognized water works or public health standards. There is, therefore, a vast variety ranging from the modern filtration plant with correct raw water conditioning through several filter plants with either inadequate or no raw water conditioning or insufficient filtering capacity to the plant that is dependent on chlorination alone for treatment. The general public is not aware that the water works in one community has far better facilities than one in another municipality yet they expect the water works personnel to produce a good safe product at all times. Consequently, the experienced

and competent operator must evaluate his plant and its advantages or shortcomings so that he may meet the problems that materialize from time to time.

Many plants rely on chlorination treatment alone to assure the safety of the water. It is rare that such a plant does not eventually have problems that cannot be adequately met. The water works personnel can only take every precaution to make sure that chlorination is carried out properly. If marginal chlorination is being used, it is always good practice in such plants to maintain the highest residual that is demanded by the Government supervising agencies. If taste control methods are required, the methods that may be used effectively at such plants are limited. In several instances, chlorination is introduced at the high lift pumps prior to the discharge of the water to the distribution system. Control is naturally difficult under such circumstances. One cannot place the blame on operators in every instance if the treatment is not totally adequate. The plant itself is inadequate for proper treatment.

There is also a wide variation in the raw water conditioning that is provided at filtration plants ranging from practically none at all to the full amount of pre-treatment. Operators must, therefore, be able to evaluate their plants and the problems that must be met in order to use it to the best of their ability. It must be remembered that plants are designed to a certain criteria and they should be operated on that basis.

Research can be of considerable aid to water works personnel either in conjunction with the Government agencies or alone. It permits a better understanding of the capabilities of the plant under every condition and the possibilities for changing the treatment to meet

differences in water quality. The responsible water works operator therefore learns to evaluate his plant and to carry out experiments that will enable him to use the facilities to their best advantage.

SUMMARY

The major public health requirements in the operation of water treatment have been listed as follows:

A) Maintain the quality of the water to meet the standards established by public health and water works authorities.

B) Know the sources of contamination that endangers the operation of water works plant and be ready to meet the condition that is created by such pollution. In particular, do not assume that discharges from sewage treatment plants in the area are satisfactory.

C) Water works personnel should secure as much training as possible in order to be able to supervise operation to the best of their ability.

D) Water works personnel should evaluate the capabilities of their plant and carry out regular research so as to operate to its peak efficiency.

BASIC MATHEMATICS

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Mathematics is the science of calculation of quantities and is used to collectively describe the three basic sciences or arithmetic, algebra and geometry. The lecture today is concerned with reviewing many of the principles which most of you were familiar with in public school or high school.

ARITHMETIC is the study of numbers and the use of numbers to count, describe, and calculate, quantities. It includes the simple mechanical process of addition, subtraction, multiplication and division.

GEOMETRY is the study of the magnitudes of space such as lines, surfaces and planes.

ALGEBRA utilizes symbols and equations to describe the relation between quantities and to determine solutions to problems.

LONG DIVISION

We can assume that all of us are familiar with the rules of addition, subtraction and multiplication as these are necessary to conduct our daily lives. However, the basic rules of long division often escape those who do not use them daily.

Example 1

divide 13,920 by 32

or 13,920 ÷ 32

```
        435
32 | 13920
     128xx
     -----
      112
       96
     -----
       160
       160
     -----
        00
```

divisor - 32
dividend- 13,920
quotient- 435

Example 2

divide 3,565,240 by 325

```
          10,969   315/325
325 | 3565,240
      325xx
      -----
       3152
       2925
      -----
        2274
        1950
      -----
         3240
         2925
      -----
          315
```

remainder $\frac{315}{325}$

EQUATIONS

An equation is a statement of the equality of two quantities.

EXAMPLE 3 $2 + 2 = 4$

As long as the same computation is applied to each side of the equation it will remain unchanged i.e. any amount may be added to, subtracted from both sides or both sides may be multiplied or divided by the same number.

In algebra the usual form is as follows:

EXAMPLE 4 $3X = 24$

solution - divide both sides by 3

EXAMPLE 5 $\frac{x}{5} = \frac{45}{3}$ multiply both sides by 5

$$x = \frac{225}{3} = 75$$

FRACTIONS

In many cases it is impossibly to express a quantity as a whole number and we must revert to fractional numbers such as 1/4, 1/5, 1/8 etc. Difficulty is often experienced in performing the minor computations with fractions.

ADDING FRACTIONS

To add or subtract fractional numbers it is necessary to transform all the individual denominatiors to a common denominator and then add the numerators.

EXAMPLE 6 $1/4 - 3/16 + 5/8$

(a) divide each denominator into the lowest number into which all the denominators will divide.

(b) multiply both the numerator and denominator by the quotient

$4/16 - 3/16 + 10/16 = 11/16$

MULTIPLYING FRACTIONS

Multiply both the numerator and denominator together

EXAMPLE 7 $3/4 \times 2/3 = \frac{3 \times 2}{4 \times 3} = 6/12 = 1/2$

DIVIDING FRACTIONS

The numerator and denominator of the divisor are reversed (inverted) and the normal rules for multiplication apply.

EXAMPLE 8 $3/4 \div 2/3$ Or $\frac{3/4}{2/3}$

$= 3/4 \times 3/2 = 9/8 = 1\,1/8$

DECIMALS

Another method of expressing fractional numbers is by the use of decimals. Decimals express fractions in multiples of 10 i.e. tenths, hundreths and thousandths.

$1/10 = 0.1$ $1/100 = 0.01$ $1/1000 = 0.001$

As shown above a decimal fraction is denoted by a digit with a period proceeding it. The value of the decimal depends upon the position of the figures with respect to the point. For instance, if a zero is inserted between the decimal and the first figure then the decimal has been divided by 10.

$0.5 = 5/10$ or $1/2$

however $0.05 = 5/100$ or $1/20$

In addition to decimal fractions there are also mixed decimals which are whole numbers with decimal fraction. For example $12\,1/2 = 12.5$

ADDITION OF DECIMALS The number must be listed one below the other with the decimal points in a vertical line.

EXAMPLE 9 Add 131.56, 125.323, 27.6

```
 131.56
 125.323        Sum of decimal fractions
  27.6
 -------        =   1.483
 284.483
```

Subtraction is similar except only two numbers are involved.

MULTIPLICATION OF DECIMALS

This is carried out in a similar manner to ordinary multiplication and the decimal point is disregarded during the computation. Add the total number of digits to the right of the decimal points and insert the dicimal point in the answer so that there are the same number of digits to the right of the decimal.

EXAMPLE 10 multiply 3.55 x 3.2

```
   3.55
   3.2      - 3 digits to right of decimal
  -----
    710
  1065
 -------
 11.36.0    - 3 digits to right of decimal
```

DIVIDING DECIMALS

Multiply the divisor and the dividend by an appropiate multiple of ten to make the division a whole number and do likewise with the dividend.

EXAMPLE 11 divide 253.5104 ÷ 3.52

after multiplication by 100 becomes.

```
             72.02
352      ┌──────────
          25351.04
          2464x
          ----
           711
           704
           ----
             704
             704
             ---
             000
```

The decimal point in the quotient is placed directly above the decimal point in the dividend.

Changing Fractions to Decimals. Simply divide the denominator into the numerator.

RATIO AND PROPORTION

A ratio is a comparison; All of us are familiar with ratio's. For example we know that the cost of a Buick may be \$ 40000.00 while the cost of a small foreign car is \$ 2000.00 and we say that the Buick is 2 times as expensive as the smaller car.

Expressed mathematically the ratio is 2 to 1 or 2:1 and the value of the ratio is 2.

A proportion is simply a statement of equality of between two ratios. In the case of the car deal the proportion is:

$$\frac{4000}{2000} = 2/1 \quad \text{or} \quad 4000;\ 2000 = 2:1$$

In practice numerous problems are encountered in which one ratio is known and we must find an equal ratio of which only one of the items is known.

EXAMPLE 12

A table is 6 ft. long and 3 ft. wide. A table of similar shape is required with one side 8 ft. long. What will be the length of the other side ?

Table (1) $\frac{L}{W} = 6/3 = 2$

Table (2) $8/W = 2 \therefore W = 4$ ft.

PERCENT

A percent is a proportion expressed in hundredths, i.e. 1.0% = 1/100.Percent is used to provide a comparison of whole.

EXAMPLE 13

A solution is made up of:

10 lbs. of chlorine
30 lbs. of water
10 lbs. of lime

Total weight of the solution is 50 lbs.

% of chlorine	=	10/50 x 100 =	20%
% of water	=	30/50 x 100 =	60%
% of lime	=	10/50 x 100 =	20%
		Total	100%

MEASUREMENT

In order to express quantity it is necessary first to measure the material we wish to describe.

Measurements which are most commonly made are those of length, force, time, area, volume velocity and acceleration. The quantity one wishes to measure is compared against the standard units which have been set up in the past. In Canada we utilize the F.P.S. or foot, pound, second system of measurement, and the various quantities are measured as in the following units.

length	-	foot
force	-	pound
time	-	second
area	-	square feet
volume	-	cubic feet
velocity	-	feet per second
acceleration	-	feet per second per second
work	-	foot pounds

The other major system of standard units used perhaps more extensively than the British system is the metric or C.G.S. system whose basic units are the centimeter, gram and second.

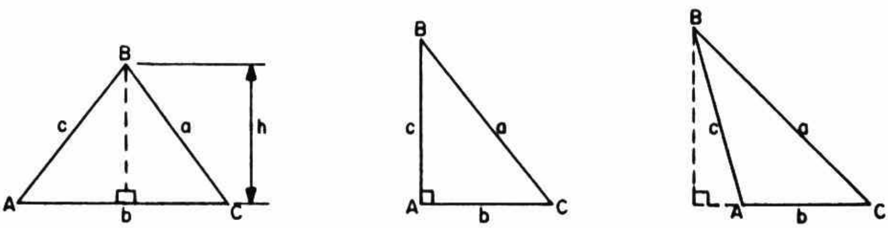
An extension of the basic measurements is outlined in TABLE I.

In order to make mathematical computations all measurements should be made within the same system of units TABLE III outlines factord which may be applied to convert from one system of units to another.

GEOMETRICAL PLANE FIGURE

A line is essentially a distance between two points and has only one dimension length.

Three Sided Figure - Triangle



perimeter - distance around the outside

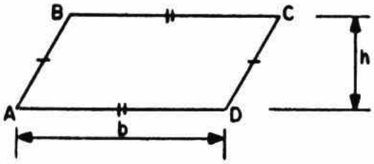
$P = a + b + c$

area - area of surface enclosed by the lines forming the sides

A - 1/2 base x altitude $= 1/2\ b\ h$

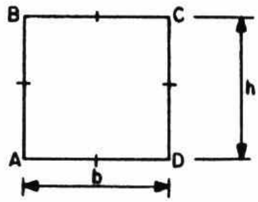
<u>Quadrilateral</u> - 4 sided figure - six special types

Parallelogram - 4 sided figure with opposite sides parallel and equal.



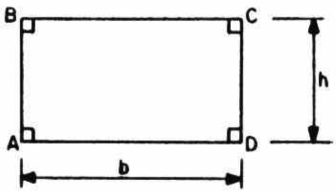
Perimeter $= 2 \times (AD + CD)$
Area $= b \times h = bh$

Square - parallelogram with all sides equal and containing four right angles



perimeter $= 4 \times b$
$b \times h = b^2$

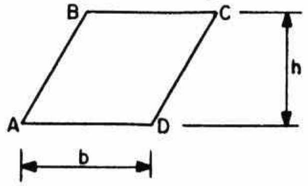
Rectangle right angled parallelogram



perimeter $= 2(AB + BC)$

area $= b \times h$

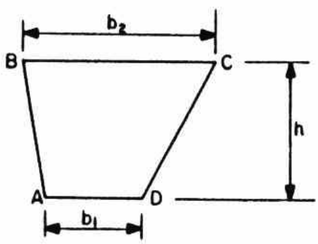
Rhombus - parallelogram with equal sides



perimeter = $4 \times b$

area = $b \times h$

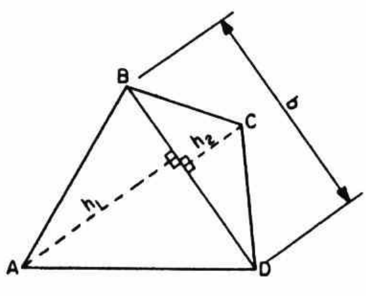
Trapezium - four sided figure with two sides parallel



perimeter AB+BC+CD + DA

area = $\frac{1}{2} h(b_1+b_2)$

Trapezoid - four sided figure with no sided parallel



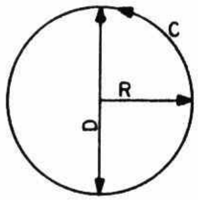
perimeter= AB+BC+CD+DA

area=area ABD+area BCO

$= \frac{1}{2} b \ (h_1 + h_2)$

1. Draw a diagonal
2. Determine the area of the two triangles thus formed
3. The sum of the triangular areas equals the area of the Trapezoid.

Circle



D = diameter
R = radius = D/2
C = circumference or perimeter

Centuries ago it was found by a mathematician that the diameter of any circle would divide into the circumference 3 1/7 approximately.

For simplicity 3 1/7 or 3.14159 was designated as

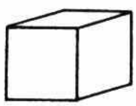
Circumference = D or 2 R.

Area = $2\ \pi R^2$ = $2 \times R \times R \times \pi$ or $\pi \frac{D^2}{4}$

THREE DIMENSIONAL GEOMETRY - Solid Figures

In most practical problems we must deal with figures having three dimensions. i.e. length, and depth. In many cases it is necessary that one can calculate the volume of tanks of various shapes, and also the areas of surfaces.

1. Cube

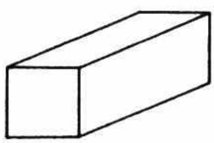


L = W = H

Volume = L X W X H
= L^3

Surface area = L X W X 6

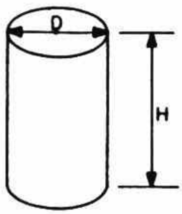
2. Rectangular Solid



Volume = L X W X H

Surface area = 2(L X W + W X H + L X H)

3.Cylinder



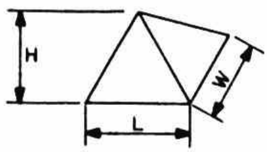
Volume=area of end X H

$= \frac{\pi D^2}{4}$ X H (off sides)

Surface area=Circumference X H

= D X H

4. Pyramid



Volume = 1/3 X L X W X H

PRACTICAL PROBLEMS

Fifty (50) lbs. of chlorine are added to a cylindrical tank 12 feet in diameter which is partially filled with water to a depth of 5 feet.

(a) What is the volume of water in the tank?

(b) How long did it take to fill this tank rising to the 5 foot level using a pump discharging at 10 gpm.

(c) What percentage of chlorine is in the tank

(a) Volume $= \frac{\pi D^2 X H}{4} = \frac{12 \times 12 \times \pi \times 5}{4} = 565$ cubic feet

100 x 10 = 1000 lb.per minute

(d) 100 gpm.$= \frac{100 \times 10}{62.4} = 16.0$ cubic feet per minute

time to fill the tank $= \frac{565}{16.0} = 35.3$ min.

(c) Weight of water = 565 x 62.4 = 35,200 lb.

Total = 35,250 lb.

percentage of chlorine = $\frac{50 \times 100}{35250}$ X 100 = .142%

2. A water treatment plant has a settling tank 25 feet long by 20 feet wide by 10 feet deep. The rate of flow through the tank is 2.0 million gallons per day.

What is the detention period in the tank?

ANSWER

Volume of tank = 20 x 25 x 10 = 5.000 cubic feet
1 cubic foot holds 6.24 gallons
volume in gallons = 50000 x 6.24 = 31.200 gallons

2.0 million gallons per day = $\frac{2,000,000}{24 \times 60}$ = 1390 gpm.

detention time = $\frac{\text{volume of tank}}{\text{rate of flow}}$ = $\frac{31200}{1390}$ = 22.4 minutes

3. A water plants treats 1.5 mgd. with 1.5 ppm. of chlorine Hypochlorite is used which contains 70% available chlorine. How many pounds of hypochlorite are required in one day?

ANSWER

1.5 ppm. = $\frac{\text{1.5 lb. chlorine}}{\text{1,000,000 lb of water}}$

or $\frac{\text{15 lbs of chlorine}}{\text{1,000,000 gal. of water}}$

$\therefore$ 1.5 mgd. = 1.5 x 15 = 22.5 lb. of chlorine

but 1 lb. of chlorine = 1/.7 = 1.43 lb. of hypochlorite

$\therefore$ 22.5 lb of chlorine = 1.43 x 22.5 = 32.175 lb. of hypochlorite

TABLE I

Weights and Measures

BRITISH SYSTEM
Linear Measure
1 foot = 12 inches
1 yards= 3 feet
5 1/2 yards = 1 rod
1760 yards = 1 mile
5280 feet = 1 mile

SQUARE MEASURE
1 square foot = 144 sq.in.
1 square yard = 9 sq. feet
30 1/4 sq.yds.= 1 sq. rod
160 sq.rods = 1 acre
640 acres = 1 square mile
43,560 sq.ft. = 1 acre

CUBIC MEASURE
1728 cubic inches=1 cubic foot
27 cubic feet = 1 cubic yard

AVOIRDUPOIS WEIGHT
1 pound = 16 ounces
1 ton = 2,000 pounds
1 pound = 7000 grains

LIQUID MEASURE
1 pint = 4 gills
1 qt. = 2 pints
1 gal. = 4 quarts

METRIC SYSTEM
Linear Measure
1 centimeter = 10 millimeters
1 meter = 100 centimeters
1 kilometer = 1000 meters

SQUARE MEASURE
1 sq.centimeter = 100 sq.millimeters
1 sq.meter = 1,000 sq.centimeter
1 sq.kilometer = 1,000,000 sq.meters

CUBIC MEASURE
1 cubic centimeter=1,000cubic millimeters (millileter)
1 cubic meter = 1,000 liters

METERIC WEIGHT
1 gram = 1,000 milligram
1 kilogram = 1,000 grams

CONVERSION FACTORS

Acres x 43,560 = square feet

Acre-feet x 43,560 = cubic feet
" " x 325,851 = gallons

Atmospheres x 29.92 = Inches of mercury
" x 33.90 = feet of water
" x 76.0 = cms of mercury
" x 14.7 = 16/sq.inch

Cubic feet x 6.24 = Imp.gals.
" " x 1728 = cu.ins.
" " x0.03704 = cu.yards
" " x 28.32 = litres

Cubic feet/sc x 0.538=M.G.D.(Imp)
" " x 374.4=gal/min(Imp)

Cubic yards x 27 = cubic feet
x 168.48 = Imp.gal.

(degrees Fahrenheit-32)
x 5/9 = degrees centigrade

(degrees Centigrade
x 9/5)+32=degrees Fahrenheit

Feet of water x 0.8826=Inches mercury
" " x 0.4335=Ib/sq.in.
" " x 62.4 =Ib/sq.ft.
" " x 9.9295=atmospheres

gallons (Imp) x 0.1603=cu.ft.
" x 277 =cu.ins.

gallons (Imp) x 1,2000095=U.S.gals.
gallons(U.S) x 0.83267 =Imp.gals.
gal.(Imp)waterx 10 =lbs.water

gals/min (Imp)x0.002673 =cu.ft./sec
" " x9.618 =cu.ft./hr.
" " x1440 =gals/day
grains/Imp.galx14.285 =part/million
" " " x142.85 =lb/million gal.

Pounds x 16 = ounces
x 7000= grains
x 453.59.24= grams

Pounds of water x 0.01602 = cu.ft.
x 27.68 = cu.ins
x 0.1439 = gals.(Imp)

Pounds/sq.ins. x 2.307 = feet of water
x 2.036 = ins.mercury
x 0.06804 = atmosphere

Grams x 15.43 = grains
x 0.03527 = ounces
Grams/litre x 70.1 = grains/gal.(Imp)
" " x 10.014 = lb/1000 gal(lmp)
" " x 1000 = parts/million

Inches x 2.54 = centimeteres
Inches mercury x 1.133 = feet/water
x 0.4912 = lb./sq.
Inches water x 0.07355 = ins.mercury
x 0.03613 = lb./sq/.
Kilograms x 2.205 = lbs.

Litres x 0.220 = gals.(Imp)
x 61.02 = cu.ins.
x 0.03541 = cu.ft.
Metres x 3.281 = feet
x 39.37 = inches

Miles x 5280 = feet

milligrams/litre x 1 = parts/million
M.G.D.(Imp) x 1.86 = cu.ft./sec.
" " x 694 = gal/min (Imp)

Ounces(fluid)x 1.805 = cu.ins

parts/million x 10 = lbs/million gal.(Imp)
x 0.0584 = grains/U.S. gal.
x 0.07016= Imp.gal.

GROUND WATER SUPPLIES

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INTRODUCTION

Water is considered to be the most important natural resource of this province. In this discussion, we will deal mainly with that water which occurs in the saturated portions of the overburden and the rock. This water is called ground water. Because we cannot see ground water under normal conditions, we often assume that it is present in limited quantities and is really not a satisfactory water supply; however, ground water is an important source of water supply throughout the world and its use for home, farm, municipal, industrial, and irrigational supplies continues to increase. It is estimated that, at the present time, approximately 30 percent of the total water used in Ontario is ground water.

SOURCE AND MOVEMENT

Ground water is part of the hydrologic cycle. This cycle which has been called the circulatory system of the earth is shown on Figure 1. Moisture-laden air moving over the land masses from the oceans drops about 30 inches of precipitation in the form of rain and snow on North America every year. Of this amount, about three-quarters is returned to the atmosphere by direct evaporation as it falls, by evaporation from the land surface, by evaporation from bodies of surface water, by evaporation from vegetation, and by transpiration from the plants which draw water up from the soil through their roots. Of the remaining portion at least half reaches surface water bodies directly as surface runoff. Some of the remainder infiltrates into the ground to form the soil moisture which is available to vegetation and a very small amount moves downward to become ground water in the saturated zone.

Water in the saturated zone moves under the influence of gravity at rates from about five feet per day to about five feet per year until it reappears at surface as a spring, or discharge into a stream, lake, or ocean. This fact is readily recognized when we observe rivers and streams continuing to flow after long periods of no rainfall. The rivers are being fed by ground water which drains slowly into the river channels, throughout the drainage system. Only during

the more intense or long rainfall periods do appreciable quantities of precipitation run off directly to streams without passing through the ground. It is very important to keep in mind that ground water and surface water are not separate and distinct but closely interrelated.

STORAGE

It can be seen that, as part of the hydrologic cycle, ground water is a renewable natural resource and the amount that finally flows out on surface or is extracted by means of wells is usually replaced every year. If we assume that about half of the precipitation that reaches the earth's surface infiltrates into the ground, this would mean that for every square mile of land surface 65 million gallons of water per year would infiltrate. This figure, however, is controlled by such factors as topography, soil type, vegetal cover, and geological conditions. Where sand and gravel deposits are present at surface or where bedrock formations with their weathered surfaces outcrop, a maximum amount of infiltration will take place. On the other hand, surface deposits of clay or clay-till will contribute to a greater amount of surface runoff.

As mentioned earlier, ground water is stored in the pore spaces between the sand and clay particles and in the crevices and solution channels of the rock formations. Poorly sorted sand, gravel, silt, and clay materials such as occur in till, a glacial deposit, where large and small particles of soil are mixed together, have a smaller proportion of pore space in which water can be stored than in well-sorted materials where all the grain sizes are equal. Figure 2 shows several types of overburden and rock interstices and the relationship of texture to porosity.

A general range in porosity of natural sediments and sedimentary rocks is given in Table 1.

TABLE 1

Materials	Porosity Percent
Sandstone	4-30
Sand, clean and uniform	30-40+
Gravel, clean and uniform	30-40+
Sand and gravel mixed	15-25
Silt and clay	
As deposited	40-90
Compacted and dewatered	20-40
Shale	1-35
Limestone	1-50

A formation may contain many pore spaces which contain a great deal of water but if the pores are small or not connected so water can flow freely from one pore to another, the formation may yield only a small amount of water. This introduces the second very important factor used in determining how a formation will act as a source of water. It is called permeability - the ability of a formation to transmit water. A formation such as sand and gravel or creviced limestone which has many pore spaces which are sufficiently large and interconnected to allow ground water to move freely through them is called an aquifer.

Most of us know very little of the amount of water stored in these aquifers or ground-water reservoirs. The Ontario Water Resources Commission and government agencies in several other provinces, notably Alberta and Saskatchewan, are stepping up their collection of basic data and making an inventory of ground-water conditions by means of geologic and hydrologic surveys. Some idea of the amount of water in storage may be obtained from a statement in the U.S. Department of Agriculture Year Book in 1955, ---- "The ground-water reservoirs of the United States contain far more fresh water than the capacity of all the nation's reservoirs and lakes, including the Great Lakes. It has been estimated that the total usable water in storage is of the order of 10 year's annual precipitation or 30 year's runoff."

WATER-BEARING PROPERTIES OF ROCK FORMATIONS

The Precambrian granites and other intrusive, sedimentary, and volcanic rocks underlie 60 percent of the area of the province, chiefly in northern Ontario. As a rule, these formations are classified as poor aquifers. Wells may obtain sufficient water for average domestic needs from joints, cracks, or fracture planes near the surface of these rocks but high capacity wells are confined almost entirely to the sand and gravel deposits in the overburden above them.

The limestones and dolimites of southern Ontario vary widely in their water-yielding properties. They often make better aquifers in the southwestern parts of the province than they do in south-central or eastern Ontario. The quality of the water is generally very hard and is often highly mineralized with sulphur compounds, particularly in the areas closest to lakes Erie and Ontario and the St.Lawrence River.

The shale formations yield only small quantities of water but the water is much softer than that from the limestone rocks. Salty water is frequently encountered at shallow penetrations of shale formations.

A wide variety of overburden conditions is present in Ontario. Although much of the area is covered on the surface of the ground with clay or till materials, numerous deposits of sand and gravel are present on top of or within the over-

burden to provide in most places suitable aquifers for average domestic needs. Areas where there are high capacity wells for municipal, industrial, or irrigational purposes are necessarily more restricted.

EXTRACTION OF GROUND WATER

Aside from the utilization of naturally occurring springs, ground water is recovered by means of dug, bored, driven, and drilled wells. Although there are more dug wells in use today, probably, than any other type, the number of drilled, driven, and bored wells is increasing as a result of improved methods of well construction and the need for deeper wells which provide a more dependable supply of water. The dug, bored, and driven types of wells are normally the least satisfactory because they are usually the shallowest and are most easily affected by variations in ground-water levels. These types of wells work best in areas where there is sand and gravel in the overburden. Under these conditions, the porosity and permeability are such that water is able to move into the well quickly to replace that which is withdrawn. Dug,bored, and driven wells in areas of tight, clayey overburden are often without water because the transmissibility of the clay is so small that water will not flow into the well readily; however, a few sandy seams in the clay will often keep the well supplied.

Often more reliable sources of water supply are available from drilled wells. Drilled wells usually extend deeper than dug wells into what are known as artesian aquifers. By this we mean that the water is coming from horizons either in the overburden or the bedrock that are confined by impervious strata or aquicludes. The water in a well drilled into an artesian aquifer rises up above the level where it was first encountered, because of the pressure behind it. If the pressure head is great enough, the well will flow. The flowing well is not an indication that the well is good but that the well head is lower than the pressure head of the water in the aquifer at that point.

Drilled wells ending is sand and gravel are sometimes developed with an artifical gravel pack to reduce the velocity of water flow into the well. This helps to keep the water free from sand and silt and the screen free from materials precipitating out of solution. Other wells drilled into sand and gravel are developed naturally with no gravel pack. The rock well requires no screen and, therefore, usually requires less maintenance and rehabilitation.

When water is pumped out of a well, the lowering of water pressure at the well site causes water in the aquifer to flow towards it. It is only natural, therefore, that there will be a lowering of the water level or water pressure in the vicinity of any pumped well. This lowering forms a cone

of depression which varies in size according to the rate at which the well is pumped and the permeability of the aquifer. In a water-table aquifer, that is one that is not confined, pumping will actually cause a dewatering of the aquifer itself and the cone of depression will spread very slowly. In an artesian or confined aquifer, which is the type into which many, if not most, of our municipal drilled wells are constructed, the cone of depression is an imaginary pressure surface that spreads out rapidly. In the confined or artesian aquifer the effect of pumping can be observed several hundred feet away in a few minutes.

Figure 3 shows the effect of a pumped well on the water levels in adjacent wells under water-table and artesian conditions.

PUMPING TESTS

When a well is constructed, a pumping test should be conducted to determine the permeability and storage coefficients of the aquifer. These coefficients tell us how fast the aquifer allows the water to move through it and how much of the water stored in the pores and crevices of the saturated formation is available for use. On the basis of the information obtained from a pumping test it should be possible to give a fairly accurate rating as to the capacity of the well. In such tests, many readings should be taken of water levels in the pumped well and preferably one or more gauge holes, particularly during the early part of the pumping test.

After a well has been put into use, the following observations should be made as regularly as possible:

1) Daily quantity pumped
2) Daily pumping level
3) Daily discharge pressure
4) Weekly static level

Unless these data have been recorded in a careful and orderly manner, it is very difficult to assess the cause of well failures and production decreases.

If production from a well drops off and the static level remains about the same, the trouble could be due to a faulty pump or plugging of the well. In case of pump trouble an experienced pump mechanic should be consulted. If it appears that the well is being gradually plugged with iron or lime scale or with silt and sand particles, some form of chemical or mechanical treatment will be required to rehabilitate the well. Well problems and well maintenance are the subjects of a lecture in a later course and we will not take time to discuss them further here.

GROUND-WATER RECHARGE

If we consider that about 9 inches of water is available annually from precipitation for use in our streams and ground water, this amounts to about 130,000,000 gallons on each aquare mile of land surface. If we assume at least one half of this amount infiltrates the ground to an aquifer, we have a better understanding of where the recharge comes from that replaces the water removed by pumping. An interesting fact is that the average annual recharge period extends from November to May. Most of the rain that falls during the summer and fall months never reaches the zone of saturation because it is used up mostly as soil moisture.

If the static level, or the level to which the water rises when the well is not being pumped, is gradually lowering in a well, it indicates that more water is being removed from the aquifer than is entering by natural recharge. The lowering of ground-water levels in the vicinity of pumped wells is not necessarily something to be alarmed at providing at some time the ever widening cone of depression finally includes sufficient recharge to balance the withdrawals. This may take place if the cone extends to intersect a body of surface water.

Just as in a surface reservoir or lake it is perfectly feasible to draw on stored water during periods of drought with a consequent lowering of the water level, a similar drawing on storage from an aquifer would lower the level of the water table. The falling water tables we hear about are not unexpected during periods of low recharge; however, during wet years the storage tends to be replenished.

Water levels that continue to lower and do not show the effect of recharge indicate the mining of ground water. The continuation of such over-drafts will either lower the water level to the limit of economic lift or will exhaust the stored water.

It should be pointed out here that many aquifers can be recharged by artificial means either in pits similar to those in use at Aylmer, London, and Trenton or by means of wells like those in use at Aylmer, Dresden, and Forest. The hydraulics of ground water is a very important study which increases our knowledge of the relationship of ground-water supplies to their extraction through wells. It is the subject of a lecture for a more advanced course.

WATER QUALITY

Water moving through the atmosphere and the soil particles comes into contact with many soluble materials. These form chemical compounds, or salts, which are contained in solution.

Some rocks are more soluble than others. Granites and other igneous rocks are relatively insoluble but limestone, gypsum, and dolomite can be quite soluble. Over long periods of time, considerable amounts of calcium carbonate or sulphate are taken into solution from these rocks.

The hardness of water is due to the presence of bicarbonate and carbonate salts of calcium and magnesium and tha alkaline-earth sulphates, chlorides, etc. The former contribute to the "Carbonate" or "temporary" hardness and the latter to the "non-carbonate" or "permanent" hardness.

Ground water is usually very hard. A hardness scale in common use is as follows:

	Hardness
Soft water	0 - 60 ppm of $Ca\ CO_3$
Medium or moderately hard water	61 - 120 " " " "
Hard water	121 - 180 " " " "
Very hard water	greater than 180 " "

Depending on geological conditions, ground water may also contain amounts of hydrogen sulphide, salt, or iron.

WATER USE

The principal uses of ground water are for domestic, farm, municipal, industrial, and irrigational purposes. The use of ground water has increased in recent years in Ontario particularly in parts of southwestern Ontario. This has contributed to problems of water rights in common with surface water supplies.

Irrigational use is to a large degree consumptive use in that the water is lost by evaporation and transpiration and does not return to the aquifer.

Industrial, municipal, and other uses of water have also increased but their effect on water supply is not as pronounced as irrigational use as most of it is returned to either surface or ground-water sources again. Re-use of ground water is practised to a greater degree in some other countries than in Canada.

Approximately 30 percent of the people in Ontario use ground water. If we were to consider only those served by municipal water-works systems, this percentage is reduced to about 17. In 1958, 164 communities, out of a total of 409, were served entirely by ground water. There are probably more than these being served at the present time. A comparison of ground-water use with other sources of supply is shown in Table 2.

About seventy-seven percent of the well supplies were untreated, about 20 percent required chlorination only, and

about 3 percent had iron removal, aeration, or softening with or without chlorination.

CONCLUSIONS

In conclusion, we may say that ground-water supplies in Ontario are very important to its economy. Although tremendous quantities are unused, we do not know exactly what these reserves amount to. Ground-water investigations will have to be greatly increased before this information is known.

Ground water is a renewable resource. Within limits of local precipitation and geologic conditions, ground-water reservoirs can be lowered annually without endangering the supply provided the withdrawals are equal to the average perennial recharge.

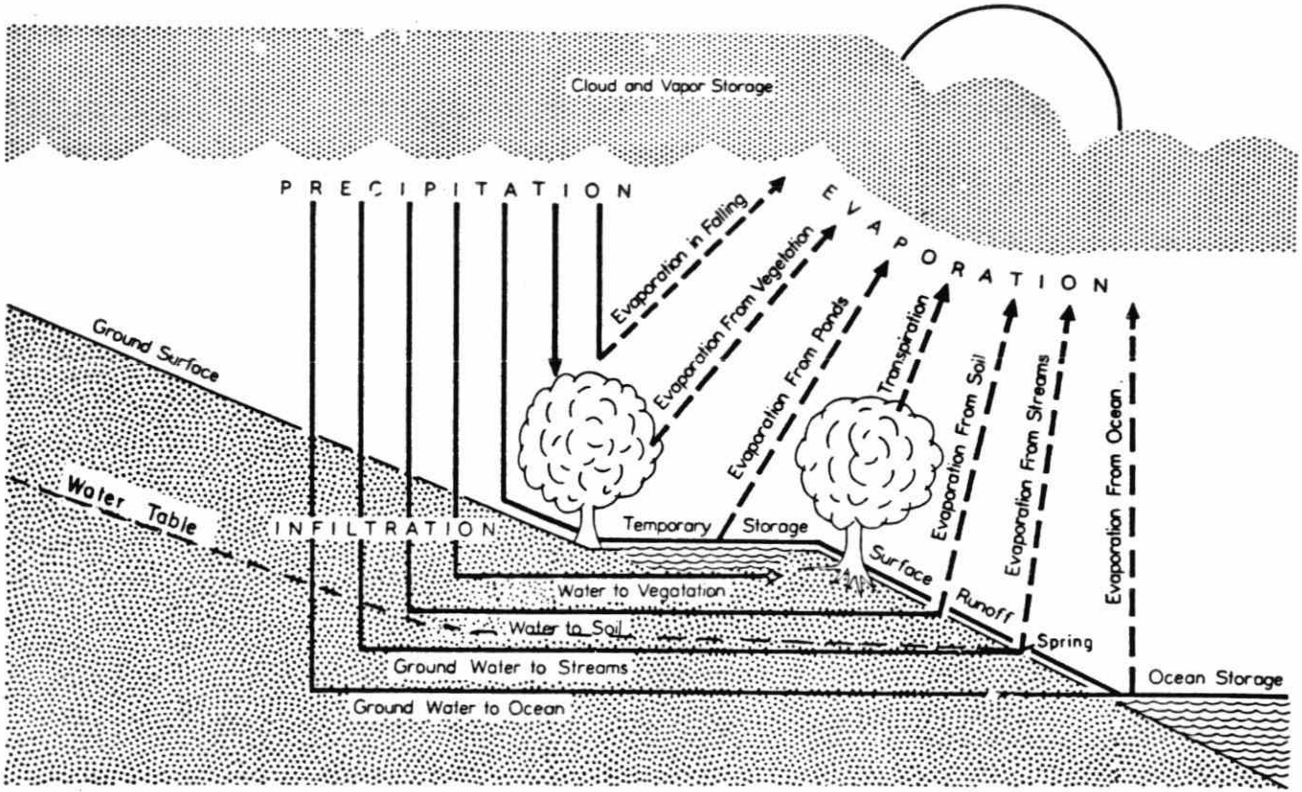
Finally, although ground water is usually very hard and may contain other undesirable chemical constituents, the advantages of cool and constant temperatures along with the economy of setting up and operating the water-works system usually make it the preferred source of supply if the desired quantity of water is assured.

TABLE 2. Communities Served by Water Works Systems
Listed According to Source, 1958

Source	Number of Communities	Percent of Total	Estimated Population Served	Percent of Total Served
Ground	164	40.1	668,520	16.6
Inland Lakes and Rivers	115	28.1	878,670	21.9
Great Lakes System	130	31.8	2,463,450	61.5
Total	409		4,010,640	

THE HYDROLOGIC CYCLE

Figure 1



Courtesy of the U.S. Geological Survey

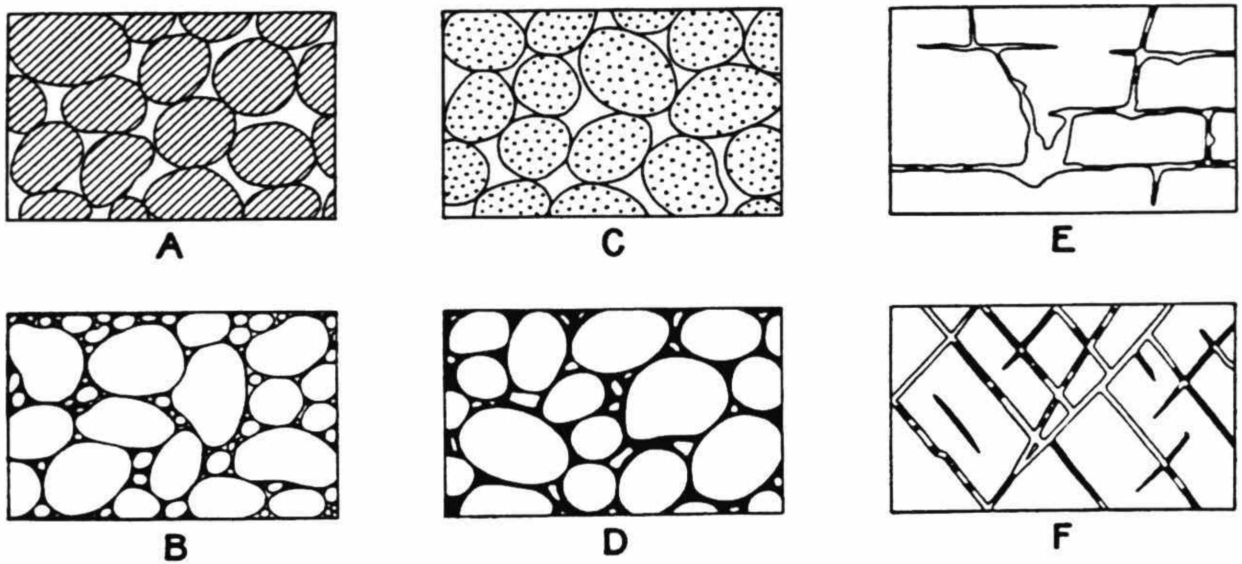


Figure 2—Diagram showing several types of rock interstices and the relations of rock texture to porosity.

A—Well-sorted sedimentary deposit having high porosity.

B—Poorly sorted sedimentary deposit having low porosity.

C—Well-sorted sedimentary deposit consisting of pebbles that are themselves porous; the deposit, as a whole, has a very high porosity.

D—Well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices.

E—Rock rendered porous by solution.

F—Rock rendered porous by fracturing.

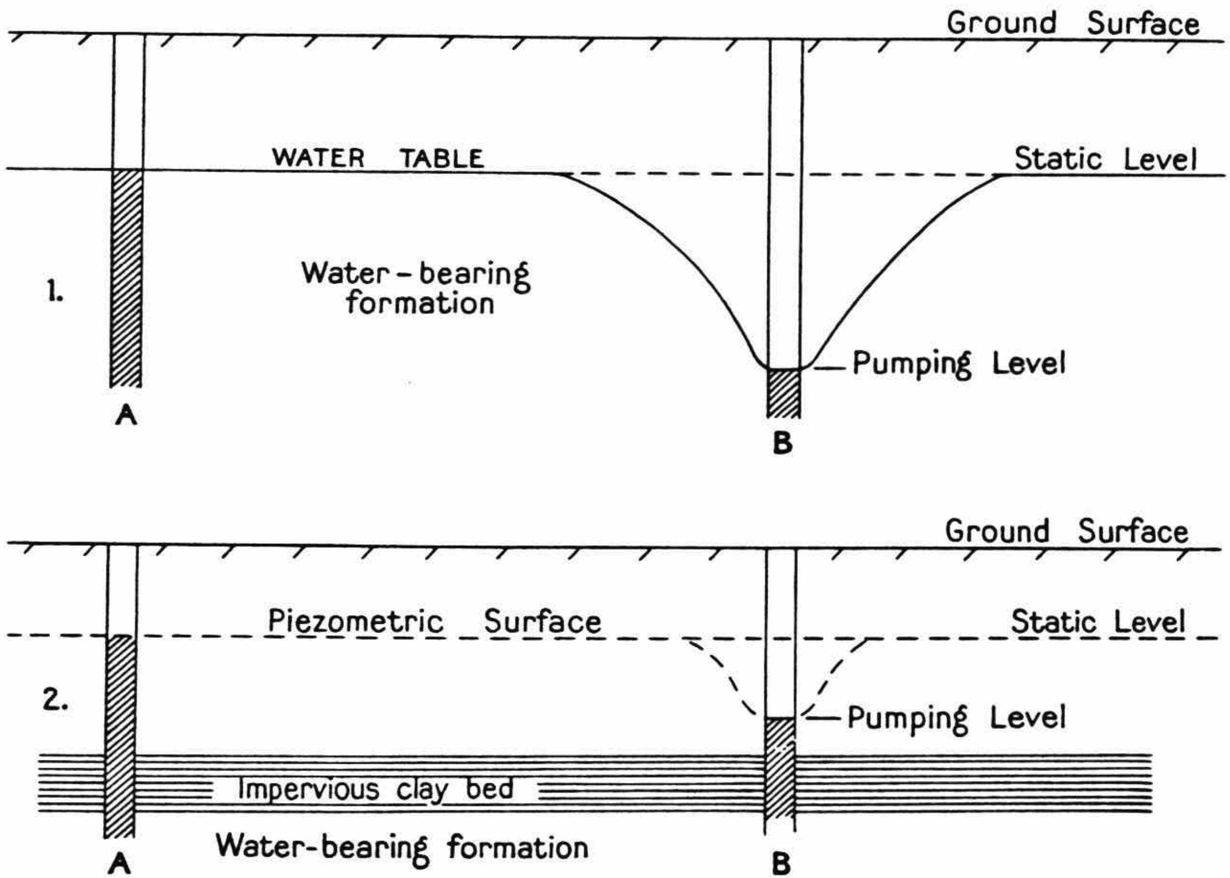


FIGURE 3 - showing the effect of a pumped well on the water levels in adjacent wells under water-table and artesian conditions.

SURFACE WATER SUPPLIES

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Quantity, quality and intakes, these are the four headings under which surface water is discussed in this lecture.

By definition, surface water is that portion of water in a liquid state which appears on the surface of the earth. It may be fresh water as it occurs in the streams, rivers and lakes in Ontario or salt water such as the water of James and Hudson bays. With the abundant supplies of fresh water in Ontario there is little interest in salt water which would require costly desalinization treatment for most uses.

Precipitation is most commonly thought of as the origin of surface water and it is true that a large part of surface water fell, as precipitation, either directly on bodies of surface water or on adjacent lands and drained directly into streams and lakes. However, a substantial portion has at some time been ground water. The path that water has taken is a significant factor in determining its quality and dependability. As an example compare the cool, clear water and good year-round flow of streams which are fed by springs and ground-water seepage with the turbid flood water and low summer flows of streams depending primarily on direct overland runoff.

SURFACE WATER QUANTITY

A few general statistics on Ontario's water supply will be of interest.

The average annual precipitation in Southern Ontario is about 33 inches. The average discharge from the Great Lakes Basin at Cornwall is 241,000 cfs. which is equivalent to 11 inches of water per year over the drainage basin. By subtraction, approximately 22 inches of water are returned to the atmosphere by evaporation or transpiration.

In addition to having our surface water resources renewed by nature at reasonably regular intervals, by precipitation, vast quantities of water are held in storage in the lakes and additional quantities are moving through the ground to discharge to streams. It is apparent that Ontario has an abundant water resource.

Records of precipitation are assembled by the Meterological Branch, Department of Transport. Streamflow records are collected and published by the Water Resources Branch, Department of Northern Affairs and National Resources. Water levels of the Great Lakes and navigable waterways are recorded by the Canadian Hydrographic Service, Department of Mines and Technical Surveys. The navigation charts of the Service are a useful reference for initial intake studies.

Now let us take a quick look at water requirements. The average person requires 3 to 5 pints of water per day. Part of this may be derived from foods. In a home without a pressure system to supply water, normal usage is about 10 gallons of water per capita per day. In a residential village the average range of use is 40 to 60 gallons per capita per day. In cities, a range of 100 to 200 gallons per capita per day reflects industrial use. The United States Public Health Service predicts a per capita consumption rate of 153 imperial gallons per day by 1980. If Ontario is assumed to have a population of 6 million, and this rate of use is applied, total daily requirements would then be close to one billion gallons per day or 1,700 cubic feet per second. This is less than the mean annual flow in the Grand River (2,000 cfs.), or 1/100 of the mean annual flow in the Niagara River.

SURFACE WATER QUALITY

The quality of surface water varies widely from stream to river to lake, from drainage basin to drainage basin and with time at the same location. Some factors influencing quality are natural, others artificial.

Small spring fed upland streams normally yield a clear palatable water. Rain storms may cause an increase in solids and turbidity. Any bacteria present are not usually Pathogenic to humans.

Larger streams usually drain inhabited areas and are subject to more serious types of pollution. Wastewater of a sanitary or industrial nature may be modifying the original water quality.

The quality of water from lakes, ponds and artificial reservoirs may be somewhat improved because of the effect of natural sedimentation. Here, care must be taken to avoid pollution from local sources which are usually near the shore. Prime examples of good lake sources are the Great Lakes.

A sanitary survey of the potential supply should always be conducted and quality related to current studies. The survey should include sampling under a variety of conditions.

The qualities important to municipal water supply can be classed as biological, physical, chemical and those related to radioactivity. Others have discussed water quality in relation to public health. Some further consideration of quality in terms of the surface water source is pertinent.

Biological quality -

Biological quality includes bacterial quality and factors related to plankton and aquatic vegetation.

For obvious reasons, water of the best bacterial quality should be sought. In rivers, the intake should be upstream from the area of development. In lakes, the intake should be located and extended to avoid the normal paths of polluted waters. These comments apply equally for other quality aspects.

Every surface water supply requires chlorination as minimum treatment. Chlorination and efficient coagulation, sedimentation and filtration in a modern type of filtration plant are becoming increasingly important as our population grows. Virus removal or inactivation is dependent on complete treatment.

Standards are sometimes used as guides to relate bacterial water quality to treatment. It is apparent that as quality deteriorates, additional treatment becomes essential. The application of sanitary engineering principles to each situation is more important than using a general rule.

Plankton may have a pronounced influence in the suitability of water for a municipal source and on the cost of treatment. Many of you have experienced problems associated with algae. The same is true for aqatic vegetation. Aspects of these qualities will be reviewed in later lectures.

Physical Quality -

Of concern are the physical qualities of temperature, appearance (colour and turbidity) and taste and odour.

Temperature is important to the palatability of the water and to some industrial uses. Cool or cold water is desirable. In a turbulent stream, little choice is available. In lakes, the deeper intake generally produces cooler waters. The minimum water temperature is usually just above the freezing point at 32°F. The upper values range with source; Lake Superior - 60°F; Lake Ontario - 70°F; Lake Erie - up to 80°F. Streams, except for spring-fed creeks usually rise to the 70° - 80° range.

Colour may result from a number of natural or artificial causes. The waters of northern Ontario have a distinct brown hue that requires effective coagulation for removal. This colour is often related to marsh sources. Iron is sometimes responsible for colour. Some industrial wastes are highly coloured.

Turbidity is the term applied to describe the presence of substances in water which interfere with its clarity. It is most frequently associated with soil solids being carried in the water. The upflow type of clarifier has application where moderate to high levels of turbidity are experienced. The average annual turbidity levels for most waters drawn from Lake Ontario are below 10 p.p.m. At the R.C. Harris (Toronto) plant, the annual average range from 2.2 to 7.3 Extreme levels are recorded during flood periods. After Hurricane Hazel, the turbidity along Lake Ontario exceeded 3,000 p.p.m. at some intakes.

Chemical Qualities -

Some chemical qualities are of significance. Hardness, iron, chlorides, sulphides, phenol, pH, acidity, alkalinity and fluorides are qualities usually checked. Further analysis for a variety of inorganic, organic and toxid compounds may be indicated from a study of local conditions. Some of these qualities are related to health, others to taste, appearance, treatment or use. The results of determinations for dissolved oxygen, biochemical oxygen demand and components of the nitrogen cycle are useful in assessing the sanitary quality of the water.

Chlorides, sulphides and phenol may be taste factors. A measure of the corrosive property of water is provided by pH. Alkalinity is necessary for an efficient coagulation reaction. Fluorides are related to dental carries. Hardness is important to domestic and industrial uses.

These characteristics may fluctuate little or widely throughout the year. Hardness in the Great Lakes increases to a maximum of about 125 p.p.m. in Lake Ontario and decreases as the softer water (55 p.p.m.) of the Ottawa River is received. The waters of the Trent River vary between 90-100 p.p.m. while those of the Grand range from 130 to 350 p.p.m. The lower figure represents quality during flood flow and the upper figure during low fall flow when the ground water contribution predominates.

The pH values of surface waters are usually above 7. An exception is the water in the Sudbury area where values as low as 4 are recorded. These are due to the leeching of sulphur compounds from local rocks.

Radioactivity -

With rapid development in the nuclear field and with increasing research, power and industrial applications, this phase of quality is most significant. Standards are being suggested and adopted but much remains to be learned.

Quality Protection -

In Ontario, the Ontario Water Resources Commission is vested with wide authority to protect the quality of our natural waters. Objectives for water quality have been adopted in terms of both effluent and stream. A sypnosis of these objectives is appended to these notes. The intent is to avoid impairment of the waters for further beneficial use. Section 27 of The Ontario Water Resources Commission Act deals with the discharge of contaminating materials to a watercourse.

In accordance with section 28, an area surrounding a source of public water supply can be defined and prescribed for specific pollution and supply protection.

The International Joint Commission is active in matters of pollution related to the boundary waters between Canada and the United States.

SELECTION OF SOURCE

Sources of surface water for municipal supply are lakes, reservoirs, rivers, streams and ponds. Four main parameters are applied to the selection of a source and a particular intake site. These are quality, quantity, reliability and cost.

Quality -

Raw water quality is of prime importance. The more important factors have already been discussed. Most waters can be made safe and tolerable by application of a combination of treatment processes. Costs, however, may become excessive.

A sanitary survey of the area should be conducted, which would include quality sampling, outfall examination and current studies. From this the possibility of obtaining a satisfactory water can be determined and a site or sites selected for further engineering investigation.

Quantity -

The adequacy of the supply must be definite. For rivers and streams this should be based on flow measurements whenever possible. Where discharge records are not available, hydrological studies based on precipitation record may be applied. Drought and flood conditions must be considered. Artificial impounding may be required to ensure an adequate supply.

For large lakes, the visible volume of water may indicate their adequacy. For smaller lakes, a detailed hydrological study is warranted. Maximim and minimum water levels should be determined.

Reliability -

Seldom are intake works duplicated as with pumps, treatment units and feeder mains so that source and site must not present undue hazards to continuous operation. Factors for consideration are potential structural damage from waves, floods, ice or ships, and decreased capacity from blockage by ice, silt or other foreign matter.

Cost -

The quality of the water should be such that treatment is economical. Intake costs must be assessed against water quality and treatment costs.

INTAKES

The term intake refers to the portion of a surface water supply system that conveys the water from the source to the raw water (pumping station) or water purification plant. It includes the actual inlet structure and the connecting conduit.

The intake is an expensive item and cannot be readily altered, enlarged or re-located. Therefore, careful planning with respect to location, capacity and construction is needed. The location may be determined by existing facilities, by economics or physical conditions. Capacity is normally provided well beyond immediate needs and in relation to projected growth. The geological conditions of the site must be examined and related to the stability of the works and construction methods.

INLET STRUCTURES

Early inlet structures were frequently elbows supported by a rock-filled crib arranged to draw water at some height above the lake bottom. High entrance velocity encouraged ice, sticks, fish etc. to be drawn into the intake. Where screens were provided these proved troublesome.

Through experience improved designs have been developed. The elbow has been replaced or supplemented by an expanding bell mouth. Spaced above this opening, a cover plate is placed so that water enters horizontally around a cylinder of large area. A low inlet velocity is obtained in the range of 6 inches per second. Vertical currents and vortices are avoided. The materials used may be cast iron, steel or concrete or a combination of these.

The importance of keeping the opening some distance above the lake bottom was recently confirmed at a Lake Erie intake where a construction error occured and silting of the conduit resulted.

Tower type intakes are sometimes employed. The inlet structure rises to and above the water level. Ports and gates are provided so that the level from which water is drawn can be selected.

The bellmouth intake with the horizontal top plate may be suitable for a deep river but in smaller rivers a different type of structure is used. The plane of the opening is placed vertically in the line of current. Again a cone is used to reduce entrance velocity. In special instances the inlet may be a port in a wall, dam or other structure.

Coarse bar screens may be provided at the inlet but screening, if provided, should be at the shore end of the intake works.

INTAKE CONDUIT

Cast iron pipe is commonly used for small intakes. Plastic has also been employed. Steel pipe is common for larger sizes. Some protection against corrosion such as wrapping or coating may be provided. Steel has the advantage over precast concrete pipes of being light. The latter have been used with satisfaction in recent years.

Ease of installation and reliability of joints with some measure of flexibility are important. Installation costs may run $50.00 to $60.00 per foot in addition to the cost of the pipe which approximates $15.00, $17.00, and $21.00 per linear foot for 24, 30 and 36 inch diameter sizes respectively.

Bedding of the pipe is important. The conduit may be laid on the bottom or in a trench. Waves, ice, currents or navigation may dictate the installation. Excavation near shore is usually fairly deep. The trench should be carried out well beyond the point where ice damage would be expected. Tunnels are sometimes employed for sections of an intake.

The conduit should be so graded that any air can pass out of the intake. Generally speaking, the grade is upwards to suction well. If a high point is incorporated into the design, a means should be provided for bleeding off air from this point. Special valves or a separate bleeder line may be used. If this care is not taken the capacity of the intake will be seriously reduced by air binding. Air results from dissolved gasses being released due to temperature increase or pressure reduction.

INTAKE CAPACITY

The capacity of the intake should be calculated for minimum water stage (level) conditions. The friction losses for the inlet, pipe, valves and screen should be considered. Surge at the pump suction well must also be taken into account to avoid flooding of this area when pumps are stopped.

ICE HAZARDS

In cold climates, one of the greatest hazards to intakes is blockage by ice. Ice is classified as: surface, anchor and frazil.

Surface ice is of little physical hazard to the intake structure but may slow down or alter natural purification processes and reduce the quality of the water supply.

Anchor ice forms beneath the water surface on objects which radiate heat rapidly such as valves, gratings and plates. It is usually associated with shallow open water and clear cold nights.

Frazil ice or needle ice consists of submerged networks of ice crystals. Its formation is often set off by agitation or a change in velocity. It is most susceptible to movement by even slight currents and can readily be carried into an intake. Reversal of flow is sometimes employed and many designs provide for this.

In conclusion surface waters play an important role in municipal water supply. With development in Ontario, conservation practices and reservoir construction will also play a part in resource management and development and greater dependence will be placed on the Great Lakes System as a water source. Some pipe-line developments have been undertaken to serve multiple municipalities and more can be expected.

WATER BACTERIOLOGY

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BACTERIA

The word bacteria is familiar to most people even though few are aware of their appearance or function in nature. Bacteria are often thought of as synonomous to disease organisms or associated with the cause of diseases, but beyond this little more is generally known. It is true that many bacteria are the caustive agents of various diseases and infections but many many more are of value to man both commercially and in nature through their normal activity. Several large industries cater to the requirements of micro-organisms in an attempt to capitalize on their abilities to produce products such as alcohol, organic acids and antibiotics which are necessary in the life of a community. Only through the powers of these microbes is the inert gas nitrogen available to animal and plant life. Nitrogen does not exist in nature as a mineral deposit in the earth's crust, but as a gas in the planet's atmosphere. The fixed fixed form of nitrogen exists as deposits resulting from decay of masses of nitrogen fixing bacteria. The mineralization of dead organic matter in the soil, the purification of waters and the decay of vegetation is made possible through the work of these microscopic organisms. Even much of the process of the digestion of food within the animal body is brought about by the varied activities of bacteria. Imagine the chaos in nature if dead vegetation and animal life were not caused by decay by micro-organisms.

Bacteria are so wide-spread in nature that there is scarely a medium that does not support a particular flora of its own. For our purposes a definition of bacteria will include all single-celled microscopic plants, lacking true chlorophyl and capable of reproduction.

BACTERIA IN WATER

A discussion of water bacteriology naturally falls into two categories, first, that of disease and associated organisms in water, and second, of all other organisms that cause trouble in water systems, treatment processes and in ground surface waters.

An impure or non-potable water may be defined as one that is not fit for human consumption primarily because of the possible presence of pathogenic (disease) micro-organisms. Relatively few species of organisms are held to be inactive of sewage pollution. The most important of these are the coliforms, Escherichia coli, Aerobacter aerogenes, Streptococcus pyogenes, and Clostridium welchii. These organisms are quite constantly present in the intestines of man and animals. When they are found in considerable numbers in water, it may be generally concluded that there is contamination with sewage, inasmuch as they do not often continue to multiply outside of the body for very long periods after their elimination.

Disease organisms may gain access to a water supply from the air, soil, animal discharge, contact with diseased material and from sewage pollution. Whatever the disease organism, to does not occur naturally in water, nor will it exist there for long periods. These micro-organisms must therefore be transmitted to water from some outside source. Nor are intestinal organisms, such as those causing thyphoid and dysentery, the only disease producing bacteria occurring periodically in polluted water. Bacteria causing tuberculosis, plague, tetanus and virus diseases such as polimyelitis are also present at times in water in numbers to cause concern. Too often this latter group is completely ignored. The typhoid organisms causes that accute disease when it gains entrance to the intestine by oral ingestion, where drinking water can serve as a means of transportation. However, it must be remembered that water used in washing also transplant other infectious organisms, such as the tetanus bacilli, to a wound which could be as injurious to humans as typhoid. Therefore, in estimating pollution, not only is the presence of sewage to be considered, but contact of water with animals and man as well.

A pure water supply, however, seems to affect the general health of a community and to decrease its death rate wholly apart from the decrease put to the elimination of the specific diseases mentioned above. It has been noted, for example, that when a city changes from a contaminated to a pure supply, there is not only a marked decrease in the typhoid death rate, but also in some instances decreases are noted in the number of deaths from tuberculosis, pneumonia, and other diseases. In practically every instance there is a decided decrease in the total death rate. This phenomenon must be due to one of two causes. Either, disease not ordinarily regarded as being carried by water are in a certain percentage of cases so transmitted, or the use of an impure water supply so affects the average health of a community that the individuals become more readily susceptible to other diseases. It is probable that the latter is the true explanation.

The other organisms that should be included in any discussion of water bacteriology, are those present as a result of organic or inorganic substances in water. Taste and odour problems and slime growths are undesirable since they impair water movement in mains and subsequently become a nuisance to the supplier and consumer. The organisms involved here are the suplhur and iron groups in particular, as well as all the others generally present in water systems.

Potable water therefore may be said to contain no disease producing organisms and no organic or inorganic substances deleterious to health.

DETECTING POLLUTION

It has long been recognized that the presence of sewage in water can only be detected by bacteriological methods. Suspended solids, nitrates, Biochemical oxygen demand (BOD) and other chemical determinations do not positively identify sewage pollution of water, though they may help to characterize the pollution.

Many wonder why diseases organisms themselves are not used to indicate unsafe water. One of the major reasons for this is that disease organisms abound in polluted water in small numbers making their detection difficult unless large volumes of water are examined.

In the bacteriological determinations for sewage pollution, a group of bacteria that are quantitatively proportional to the amount of sewage present is commonly used. These indicator organisms are called coliforms. Coliforms were chosen over the other types of intestinal bacteria mentioned because they most closely fit the definition of the ideal indicator.

(Appendix I).

Other organisms have been suggested for use as sewage pollution indicators, but most of these have serious shortcomings.

In nature, coliforms inhabit part of the intestine, forming one of the largest group of organisms normally populating the human and animal digestive systems. In polluted water, their density is in rough propertion to the degree of sewage pollution. Coliforms occur constantly in large numbers in human and animal discharges in comparison to pathogenic bacteria which occur only periodically in quantity. They are easily detected by rapid routine procedures to be discussed, and are harmless to humans under normal circumstances. Therefore, by watching for their appearance in water through routine determinations, information of the presence or absence of sewage pollution is obtained before a dangerous level of pollution exists.

The coliform group of micro-organisms has a longer survival time in water than does the group of intestinal pathogenes. This means that their presence indicates not only current but also past pollution.

Some disadvantages in the use of coliform bacteria to detect pollution are nevertheless evident. Foremost among these is the fact that some members of the coliform family occur naturally in soil and on vegetation, as well as in the human and animal body. The existence of members of the coliform group in water could then be interpreted to mean that that supply contained either sewage or surface soil. This knowledge enchances the power of the indicator, since under conditions of flood, heavy rains, or disturbance of soil, by animal or man, the presence of coliform would indicate that disease organisms in the surrounding enviroment had access to the water supply. As mentioned earlier soil contains natural and animal-borne pathogens that could cause serious diseases should they enter the human body. Judgment regarding the type of contamintaion is easily made when a record of sampling conditions and a coliform count are available.

ENUMERATING COLIFORM ORGANISMS

Indicated Number

After their characteristics were determined, a routine method to count coliforms was established. This method is presently known as the Indicated Number. In this procedure, a sample of water is diluted according to a predetermined scheme and a portion of each dilution is transferred to tubes containing a specific nutrient broth. This solution contains growth factors required by the indicator organism, so that when it is present in the transplanted water sample, it will, by growing, produce a

visible change in the tube of broth, and when absent the tube will remain unchanged. By this method, it is possible to determine that point in successive dilutions where coliforms are diluted out of the picture. A simple mathematical calculation will then give the number of coliforms per 100 ml. of the sample. Because of the application of mathematics and the use of dilutions, the numerical result from this test gives only an approximation of the number of coliforms. Its reproducibility is poor, the results deviating from each other on occasion by as much as 1,000 per 100 ml. An Indicated Number of 1,000 per 100 ml. of sample means that coliforms are present in .1 ml. though absent in.01 ml. quantity of the sample. This method is used to a greater extent in heavily polluted waters.

Most Probable Number

The Most Probable Number procedure is a variation of the Indicated Number method were through the application of statistical methods, an attempt has been made to obtain a more accurate enumeration of the coliform organism. This procedure involves the planting of replicate (generally three or five) parallel decimal dilutions of sample water in a special nutrient broth, where, following a confirmation test, a statistical table is consulted from which the number of coliforms per 100 ml. is directly read. This analyses takes a minimum of four (4) days. The result is merely an index of the number of coliform bacteria which, more probably than any other number, would give the results shown by the laboratory examination. It is not an actual enumeration of the coliform bacteria in any given volume of samples. The value of the most probable number procedure lies primarily in giving a number of code which approximates the actual number of coliforms present. All results derived by this method may be directly compared.

It has decided advantages over the Indicated Number method since its results are more closely reproducible, and it is valuable when used in conjunction with the proper safety standards.

Membrane Filter

In recent years following the introduction of the Membrane Filter disc, a new and more rapid and more accurate method for the isolation and identification of coliforms has been developed. The method allows bacteria to be filtered from a liquid and cultured by the application of a suitable nutrient solution on the surface of the filter leaf.

This new technique has several advantages over the other methods. Large samples can be processed more easily assuring a

more accurate determination, and results can be obtained in a period of one (1) day. A direct count of organisms is obtained where no mathematical calculations are generally required.

The Membrane Filter technique has been accepted as an alternative to the Most Probable Number determination in the United States of America and its use in routine testing is gaining favour in many government agencies. Drinking water standards for membrane filter have been established in the United States. The Water Resources Commission standards will be dealt with later.

The coliform count obtained by this method is an exact measure of the organisms in the sample. The results produced by the Membrane Filter technique are lower than that of both the Most Probable Number and Indicated Number, but have proven to be more truly representative of the actual number of coliforms in samples. A factor to enable the conversion of the Most Probable Number to Membrane Filter results may be established only for a single body of water but will vary greatly with the character of the water. Therefore, the Most Probable Number count may only be compared in a general way with the Membrane Filter count.

INTERPRETATION

Most Probable Number and/or Membrane Filter coliform data of individual water samples are interpreted to mean that:

1. when total coliform densities are one or less per 100 ml. of sample, the water is safe for human and animal consumption,

2. when total coliform counts are in excess of one per 100 ml., the water is polluted and should be reexamined to establish the extent of pollution (it may require treatment before consumption),

3. where large numbers of coliforms (greater than ten per 100 ml.) are present, gross pollution exists. This water should be treated prior to consumption and measures to detect and check pollution should be enforced.

It must be remembered that there is always the possibility of the presence of enteric pathogens when the water contains coliforms.

A satisfactory report on the bacteriological quality of a water supply is only obtained when frequent regular samples are analyzed and data are accumulated that can be used as background material in the event of poor individual samples. These data are of great importance in establishing the effect of seasonal variations and other factors on the water quality.

Following poor samples, only the analyses of a series of well chosen samples will establish the water quality and aid in locating the source of contamination. Lengthy standards have been prepared to control the quality of water in this instance. When routine sampling programmes are established for water plants in Ontario these standards will then be introduced. The main recommendation resulting from these standards is to emphasize the importance of immediate corrective measures and the commencement of a daily sampling programme, in the trouble areas, until two consecutive negative samples are obtained.

OTHER POLLUTION INDICATORS

An examination for the organism called Escherichia coli is used by some laboratories to indicate non-potable water. This organism, the same as B. coli with a new name, is one member of the coliform group which is present in fecal material. It may be used to indicate recent pollution or to confirm coliform data, but since its exclusion from water does not indicate a safe water, E.coli should not be used alone to determine sewage pollution. Together with the total coliform analyses, it gives additional information of the character ot the pollutant. Among other disadvantages in the use of E.coli to indicate pollution, the density of this organism in polluted water is generally low, substantially decreasing the chances of detecting it in mildly polluted waters.

Another group of bacteria that will be discussed more fully in the next phase of this course is the fecal Streptococcus group. The detection of the present of this organism in water will aid mainly in evaluating the recency of pollution.

NUISANCE ORGANISMS IN WATER

The nuisance micro-organisms (other than algae) that generally occur in water fall into the following groups:

1. Total bacterial population,
2. Iron and magnesium bacteria,
3. Slime bacteria including molds,
4. Sulphur and sulphate reducing bacteria, and
5. Actinomycetes - the organisms responsible for the characteristic smell of earth.

All of these organisms grow in water as a result of a particular set of conditions created in the water. These have been studied by many research workers though little practical information is available from their investigations.

The identification of many of these bio-fouling organisms is very difficult though some of their properties may be determined. Chemical and physical contact have not been widely studied, with the result that chlorination and good-housekeeping still remain the only available effective means of treatment.

A P P E N D I X I

Characteristics of Coliforms as a Pollution Indicator Compared to the Ideal

	The Ideal Indicator	The Coliform Indicator
1.	gives uniform results with all types of water	is affected at times by the type of water
2.	is never present in safe water	is absent in safe water
3.	density is proportional to fecal pollution	density is roughly proportional to fecal pollution, and is eliminated in large numbers in fecal wastes
4.	is harmless to man and animals	is harmless to man and animals except in very rare cases
5.	has a greater survival time in water than do disease organisms	is more resistant than most disease producing organisms
6.	disappears rapidly from water after the death or destruction of disease bacteria	generally dies off rapidly. However, some species may grow in polluted water
7.	distribution is restricted to one type of waste	is widely distributed in nature but always present in human and animal discharges
8.	is easily detected by routine methods	is relatively easy to detect by routine procedures

BASIC HYDRAULICS

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INTRODUCTION

Hydraulics is the science of fluid flow, and although the general principles involved can apply equally to fluids, gases and vapours, we shall consider only the most common fluid-water.

A great number of operators and others engaged in the water works field look upon hydraulics as a formidable, incomprehensible subject. This is unfortunate for the vast majority of everyday water works problems can be solved with a knowledge of arithmetic and some introduction to high-school algebra. The trouble appears to be not so much in the technical difficulties of calculations as in the understanding and application of the general principles of hydraulics.

Often we run into calculations where there appears to be too many unknown quantities. For most pipe line and pumping calculations it is necessary to assume a value for one of the unknowns and to solve the problem by trial and error.

The subject of hydraulics will be discussed at each of the three water works courses. On this Basic Course we will cover the topics of fluid properties, fluid pressure and manometers. The lecture on the Intermediate Course will cover the derivation of the fundamental equations for the flow of an incompressible ideal fluid. Finally, on the Senior Course we will consider flow of a real fluid and some actual distribution system problems.

The flow of water in pipes or channels when not under pressure is limited in the water works field to some gravity supply lines and to gravity treatment plants. Open channel flow will not be discussed because of its lack of application for most operators in attendance.

FLUID PROPERTIES

1. The unit of mass (M) in the foot-pound-second system is defined as follows: A force (F) of one pound will accelerate a mass (M) of one slug at the rate of one foot per second per second (a). (By Newton's laws of motion, $F = Ma$).

2. Mass density (p (rho)) is the mass of a fluid contained in a unit volume. It is expressed in the mass-length-time system of dimensions (slug per cubic feet).

3. Unit or specific weight (W) is the weight of a fluid contained in a unit volume. It is expressed in the force-length-time system of dimensions (pounds per cubic foot).

4. Mass density and unit weight are related by the equation $p = W/g$ Where g is the acceleration due to gravity.

   or $W = pg$ The value of g varies very slightly from place to place on the earth and for all practical purposes is taken as 32.2 feet per second per second.

5. The specific volume (V) is volume per unit weight and has the dimensions of cubic feet per pound. This definition identifies specific volume as the reciprocal of unit weight

$$V = \frac{1}{W} \quad \text{or} \quad VW = 1$$

6. Specific gravity (S) is the ratio of the mass density of a substance to the mass density of distilled water at 4°C and atmosphereric pressure. Since all these items vary with temperature, temperatures must be quoted when specific gravity is used in precise calculations. It should be noted that specific gravity is a dimensionless quantity.

Specific Gravities "S" of Some Liquids at 68°F

(Referred to water at	32.2°F)
Water	0.998
Mercury	13.546
Ethyl Alcohol	0.789

If P_1 is taken as the pressure at the liquid surface (Fig. 1B), ΔH becomes H, the vertical distance below the liquid surface to the point where the pressure is P_2.

Therefore $P_2 = W \times H$ and $H = \frac{P_2}{W}$

This equation indicates that pressure at a point in a liquid of given unit weigth is dependent solely upon the height of the liquid above the point, allowing this vertical height or "head" to be used as an indication or pressure.

The expression P/W is called the pressure head. It expressed the depth in feet of a liquid of unit weight W required to produce a pressure P.

Absolute and Gauge Pressures

The mercury barometer is used to measure absolute pressure. The mercury barometer is constructed by filling the tube with air-free mercury and inverting it with its open end beneath the mercury surface of the receptacle.

Vaporization of the mercury being neglected, the space in the top of the tube is thus completely evacuated and there is nothing whatever to exert pressure in the space thus the pressure here is the lowest possible, called "absolute zero".

Since the mercury column H is in balance with the atmosphere pressure and since the pressure at the top of the column is close to absolute zero, it is evident that the length of the column is a direct measure of "pressure above absolute zero or "absolute pressure".

If p = atmosphereic pressure = 14.7 psi.(The atmospheric pressure varies somewhat with weather and altitude.)

$$H = p/W$$

$$= \frac{14.7 \text{ lbs/in}^2 \times 144 \text{ in}^2/\text{ft}^2}{13.54 \times 62.45 \text{ lbs/ft}^3} = 2.50 \text{ feet} = 29.9 \text{ inches}$$

If the column is of water and the vapour pressure of the water is neglegted:

$$H = \frac{14.7 \times 144}{62.45} = 33.9 \text{ feet}$$

One cubic foot of pure water weighs 62.45 pounds. Therefore the unit weight of other liquids may be readily calculated by the expression:

$$W\ (lb/ft^3) = S \times 62.45\ (lb/ft^3).$$

It is very important to use the right units for the known factors when solving equations, otherwise the answers will not be correct.

HYDROSTATICS

Hydrostatics is the branch of hydraulics which deals with the pressures and forces resulting from the weight of a fluid at rest.

Fluid Pressure

The force per unit area acting on a real or imaginary surface within a fluid is called intensity or pressure or simply pressure.

The pressure variation with depth within a liquid (Fig.1A) may be evaluated by considering the forces acting on a vertical prism of height H and cross-sectional area Δa. The summation of all forces acting on this prism in the vertical direction, as well as in all directions must be equal to zero. The vertical forces consist of the weight and the force due to the pressure P_1 at the top and that due to P_2 at the bottom.

Therefore $P_2\ (lbs/ft^2) \times \Delta a\ (ft^2) = W\ lbs/ft^3) \times \Delta H$ $(ft) \times \Delta a\ (ft^2) + P_1\ (lbs/ft^2 \times \Delta a\ (ft^2)$

and $P_2 = W \times \Delta H + P_1$
(the downward direction of H being taken as positive)

and $\Delta H = \dfrac{P_2 - P_1}{W}$ and $P_2 - P_1 = W \times \Delta H$

This equation embodied certain basic and familiar facts concerning fluids at rest. If H = o, the pressure difference is zero. Thus pressure is constant over horizontal planes in a fluid. Conversely if the pressure is constant over a horizontal plane, the height of fluid above the plane is constant resulting in a tendency of liquids to "seek their own levels".

If the pressure p is 1 psi

$$H = \frac{1 \times 144}{62.45} = 2.31 \text{ feet}$$

It should be remembered that standard atmospheric pressure is approximately 14.7 psi, 29.9 inches of mercury and 33.9 feet of water. Also 1 psi. is approximately equal to 2.31 feet of water.

More commonly used in engineering work is the gauge pressure. In the gauge or relative system if pressure measurement, the atmospheric pressure becomes the zero of pressure. The reading for pressure greater than atmospheric is positive and is called "gauge pressure" or simply "pressure" and is usually measured in pounds per square inch. The reading for pressure less than atmospheric is negative and is designated as "vacuum". it is usually measured in inches of mercury.

The two systems of pressure measurements may be converted from one to the other by the following expression:

$$\text{Absolute pressure} = \text{Atmospheric pressure} \; \begin{matrix} - \text{ Vacuum} \\ + \text{ Gauge pressure} \end{matrix}$$

These relationships are illustrated in Fig. 3.

Example:

A Bourdon gauge registers a vacuum of 12.5 inches of mercury when the barometric pressure is 14.5 psi. What is the absolute pressure?

$$\begin{aligned} & \qquad \text{Atmospheric pressure} - \text{Vacuum} \\ \text{Absolute pressure} &= 14.50 \text{ (psi)} - 12.5 \text{ (inches)} \times \frac{14.7 \text{ (psi)}}{29.9 \text{ (inches)}} \\ &= 14.50 \text{ (psi)} - 6.15 \text{ (psi)} \\ &= 8.35 \text{ (psi)} \end{aligned}$$

MANOMETERS

Manometers are tubes attached to reservoirs, pipes or channels for the purpose of measuring the pressure. The equations of hydrostatics are used to determine pressures from manometer readings even though manometers are most frequently usef to measure pressures in moving fluids.

When the manometers contain only the fluid in the conduit they are frequently called piezometers. Piezometers are very sentitive pressure gauges but are impractical for the measurement of high pressures because of the excessive length of tube required.

The manometer liquid most commonly used is mercury.

Consider the U-tube manometer Fig.4 (A) in which all distances and unit weights are known and pressure P_x is to be found.

Since over horizontal planes within continuous columns of the same fluid pressures are equal, $P_1 = P_2$ and

P_1 = Px and P_2 =) x W_1H

$Px + WL = W_1H$ and

$Px = W_1H = WL$

Differential manometers are frequently used to measure the difference between two unknown pressures Px and Py as in Fig. 4 (B)

$Px + W_1L_1 = P_4 = P_5 = Py + W_2 + W_3H$

$Px - Py = W_2L_2 + W_3H - W_1L_1$

Example:

This vertical pipe line with attached gauge and manometer in Fig. 4(C) contains oil and mercury. The manometer is open to the atmosphere. What will be the gauge reading Px?

$Px + 10W\text{ oil} = W\text{ mercury} \times \frac{15}{12}$

$Px + 10\,(0.9 \times 62.4) = 13.55 \times 62.4 \times \frac{15}{12}$

$Px + 561.6 = 1056.9$

$Px = 1056.9 - 561.6$

$= 495.3\text{ lb/ft}^2\text{ (psf)} = 495.3 \left\{\frac{lb}{ft^2}\right\} \times \frac{1}{144}\frac{ft^2}{in^2}$

$= 3.43$ psi

Example: Refer to Fig. 4 (D)

$P_1 = W\text{ mercury } \frac{20}{12} + W\text{ water } \frac{8}{12} + Pw = P_2 = 0$

$Pw = (13.6 \times 62.4 \times \frac{20}{12}) - 62.4 \times 1 \times \frac{8}{12} \}$

$=- 1414 - 41$

$= -1.455$ psf gauge

or -10.1 psi gauge

ELEMENTARY WATER CHEMISTRY

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Chemistry is one of our oldest sciences being allied very closely with the science of physics. There is no fine dividing line between these sciences, and without mathematics, neither would be of much practical use. The elementary chemistry discussed, is therefore to a great extent physical chemistry, with some examples of the practical uses chemists make of mathematics.

The first, is in defining units. Because water chemists perform their analysis by measuring the weight of a substance in a measured volume of sample, the scientifically accurate way of expressing results is in milligrams per litre (mgms/L), (weight per volume units). These are the commonly used laboratory units, and for those who are aquainted with what milligram weights and litre volumes actually are, concentrations expressed in mgms/L can be visualized. A better grasp of the quantities is possible when the less precise term, parts per million (p.p.m.) is used, and this is our preference. It is at most, only slightly inaccurate. One litre of pure water at 4°C weighs 1000 gms, therefore at 4°C

$$\frac{1 \text{ mgm}}{1 \text{ litre}} = \frac{.001 \text{ gram}}{1000 \text{ grams}} = \frac{1 \text{ gram}}{1{,}000{,}000 \text{ grams}} \quad (1 \text{ p.p.m.})$$

At room temperature, because of expansion, 1 litre holds very slightly less than 1000 grams of water, actually about 998. and the hotter the water is, the less 1 litre will hold.

Also, water that is very impure (a strong solution or suspension) may weigh a good deal more than 10000 grams per litre, because of the weight of material in it.

This factor needs to be allowed for when analysing dense sludges of slurries. The best way to report analyses of these materials correctly is to dry a measured volume of the sludge,weigh the solids content, and calculate a 'dried solids' factor. This is then used to convert all the (mgm/L) values of other tests to a mathematically correct "% of dried solids value" which is usually the most appropriate way to report sludge and slurry analyses.

For practical purposes then, when the sample is at most a dilute solution in water, and volumes are measured at room temperature,

1 mgm/L is closely equivalent to 1 gram/million grams (1 p.p.m.).

One practical purpose is this; one can immediately transpose into any weight unit at all

1 grain per million grains, or
1 ounce per million ounces, or
1 ton per million tons.

The most useful is 1 pound per million pounds. Since, due to our advantageous Imperial system, 1 gallon of water weighs 10 pounds, then, 1 ppm 1 pound per 100,000 Imp.Gals. or for chlorine dosages in tenths of a part per million.

1/10 ppm = 1 lb. per 1,000,000 Imp. Gals.

The factor for an older water treatment unit, sometimes still used is: 1 Grain per Imp.Gal. = 14.25 ppm
1 Grain per U.S.Gal. = 17.12 ppm

Other useful conversions from scientific to practical units are:
for water at 4°C

	1 litre	=	1000 grams	=	2.2 lbs
÷ 1,000	1 millilitre	=	1 gram	=	0.0353 ounces
÷ 1,000	1 microlitre (λ lambda)	=	1 milligram		
÷ 1,000			1 microgram		(γ, gamma)
	1 microgram/ml		(γ/ml)	=	1 mgm/litre=ppm .

$$\frac{\text{Thus comparator disc readings in micrograms}}{\text{Volume of sample measured in ml}} = \text{ppm directly}$$

$$\text{also } 1\% = \frac{1}{100} \quad \text{or} \quad \frac{10{,}000}{1{,}000{,}000} \quad \text{or } 10{,}000 \text{ ppm.}$$

Most texts have tables for converting units. The most comprehensive is a free pocket book given out by C.I.L. "Handy Tables of Conversion Factors".

Other basic units of chemistry are that, in equations

Symbol		Quantity
H	=	1 gram of hydrogen
O	=	16 grams of oxyden
thus OH	=	17 grams of hydroxyl
and HOH	(or H_2O) =	18 grams of water

Water is, in fact, a very unusual substance, although so commonplace that it's unusual properties are overlooked. These properties are a result of its chemical structure.

A water molecule H-O-H is formed of three elemental particles held together by chemical bonds. These bonds result from the charges in the particles themselves. Oxygen has a positive nucleous, balanced in charge by an inner pair and an outer layer of six electrons surrounding the nucleous. The inner pair are evenly balanced. However, among the outer six there is room for two more, eight electrons all told, to form an evenly distributed outer layer, and oxygen tends strongly to unite with elements that have electrons to spare. Such is hydrogen, a positive nucleous balanced in charge by one electron. One oxygen atom then will unite with two hydrogens atoms "sharing" an electron with each, and each of the three atoms then has an almost balanced layer of paired electrons.

I say almost because the charges on the whole water molecule are still slightly lopsided, with two pairs of negative electrons at one end, and at the other end two pairs of electrons shared with and masked by two hydrogen atoms whose positive nucleous is projecting out. This imbalance is termed "polar", the molecule as a whole tends to act as if it had "poles".

The arrangement of hydrogen atoms and paired electrons surrounds the oxygen nucleous in a tetrahedron shape.

The exposed pairs of electrons tend to attract positive charges. Thus the positive hydrogen on other water molecules (and the positive pole on polar compounds in general) are attracted to these paired electrons and held there. These 'hydrogen bonds', between molecules of water, are about 6% as strong as the oxygen bonds inside the molecule.

The properties of water arise from the hydrogen bonding and the tetrahedral arrangement of electron pairs around the oxygen atom.

To break a bond requires energy, and in the formation of a bond energy is released, similar to static electricity or magnetism. "Like repels and unlike attracts". Attraction can be used to do work (release energy), and the attraction can only be broken by exerting force (using energy).

Take the physical state of H_2O. In water, this tendency to bond together is limited, is offset by heat. It is commonly explained that heat makes the molecules active, they bounce around so that less of the hydrogen bonds are formed. The hotter the water, the more thermal activity, the less bonding, and thus the water expands. The heat capacity absorbed in breaking these bonds (the heat required to raise water one degree) is the highest of any substance.

At the critical temperature of 212°F the loosely grouped molecules in liquid water make an abrupt transistion to freely moving individual molecules, as a gas, steam. The abrupt transition requires a lot of thermal energy to break all the hydrogen bonds and explains why water has such a high heat of evaporation (536 calories/gram). As steam or water vapour is condensed the reformation of the bonds releases the same amount of energy.

As water is cooled further and begins to form ice, all of the molecules tend to be attracted to one another by hydrogen bonds and a rigid lattice-work structure of molecule bonded to molecule solidifies. This rigid structure, full of voids, requires slightly more volume than the groups of bonded molecules in water which have some possibility of overlapping into one another "nesting". Thus ice expands 10% on freezing, at the same time releasing energy as the bonds are formed. The dire consequences of overlooking the tremendous power of the expansion of ice are well known to us all. Very few containers, be they engine-blocks or steel pipe, can withstand the pressures formed.

The fact that ice is lighter than water, and that the heat capacities of water are high have had consequences for life on this planet that are astounding when considered. The major reason our temperatures vary as little as they do is because of the tempering effects of the cooling, heating, freezing and evaporation of water. This mineral covers three-fourths of the earth's surface, sometimes to a depth of six miles, and there may be as much as 50,000 tons of water vapour above one square mile of land surface. An only slight reduction of the heat capacities of water could double our climatic temperature range from 0 to 100°F to say 50 to ±150 °F. Presuming that humans could survive, what would become of our food organisms, plant and animal crops, or of our forests. We would follow them into extinction and our "temporate" regions would become deserts.

Consider even the consequences of ice being heavier than water. Rivers and lakes would freeze from the bottom, would warm from the top, and ice would likely persist year round on our lake beds. The twice annual turnover of our lakes, which takes place spring and fall when the upper strata of water warms or cools to the same temperature (and density) as the water beneath, would not occur, and the nutrients entering our lakes would settle out and forever be lost in the bottom ice. Fish and most aquatic organisms would perish.

Other properties of water which have high values attributable to hydrogen bonding are well known to any one who has dived from a height. The combined resistances of the high density, surface tension and viscosity of water provide an impact similar to that of concrete if a poor entry is made. Think how much easier it would be to dive into a liquid similar to gasoline, light, mobile, and with low film tension, and how much harder one would hit the bottom of the tank!

The chemistry of water is mainly governed by the ability that water has to <u>dissociate</u>.

$$H_2O \rightleftharpoons H^+ + OH'$$

A very few hydrogen nucleous particles can break away from the whole molecule, each leaving it's electron behind. This loss of a negative electron leaves a positively charged (H^+) hydrogen ion. The remainder of the molecule which retains the electron becomes negatively charged forming an (OH') hydroxyl ion.

At any one time, only 1 water molecule in every 550 million is dissociated. At room temperature a relation holds between the hydrogen and hydroxyl ions. Their concentrations, expressed as H^+ and OH' symbols (see units) when multiplied together always equal.

$$\frac{1}{100,000,000,000,000} \text{ or } \frac{1}{10 \times 10 \ldots (14 \text{ times})} \text{ or } \frac{1}{10^{14}}$$

In absolutely pure water the hydrogen and hydroxyl ion concentrations are equal.

H^+ = OH' since one of each is formed from each molecule of water. The concentration of each is then

$$\frac{1}{10^{7}} \quad \text{since} \quad \frac{1}{10^{7}} \times \frac{1}{10^{7}} = \frac{1}{10^{14}}$$

If either an acid or alkali is added (H^+ or OH') then the dissociation is altered to form water and the product of the new concentrations of H^+ and OH' still = $\frac{1}{10^{14}}$. Thus when H^+ is increased OH' decreases proportionately.

When H^+ = OH' the solution is neutral
When H^+ exceeds OH' the solution is acid
When OH' exceeds H^+ the solution is basic

Concentrations by weight Hydrogen	Hydroxyl	H+ Concentration per litre	OH' Concentration per litre	pH
1%		10		-1
1,000 ppm		1		0
100 ppm		1/10		1
10 ppm		1/100		2
1 ppm		1/1000		3
100 ppb		1/10,000		4
10 ppb		1/100,000	1/1,000,000,000	5
1 ppb		1/1,000,000	1/100,000,000	6
0.1 ppb	1.7 ppb	1/10,000,000	1/10,000,000	7
etc.	17 ppb	1/100,000,000	1/1,000,000	8
	170 ppb	etc.	1/100,000	9
	1700 ppb		1/10,000	10
	17 ppm		1/1,000	11
	170 ppm		1/100	12
	1700 ppm		1/10	13
	1.7 %		1	14
	17 %		10	15
				etc.

You will observe that to avoid using long numbers in the first column, the author has jumped from ppb to ppm to %. Chemists have a better way of expressing such long numbers. All numbers can be expressed in powers of 10.

$100 = 10 \times 10 = 10^2$
$1{,}000 = 10 \times 10 \times 10 = 10^3$ etc.

By agreement $10^0 = 1$

Mathematicians have worked out the equivalents of fractional powers of 10. i.e. $10^{1.5}$ etc. and these are listed in logarithm tables.

Thus chemists define pH as a short form, taken from the power of 10 which appears in the fraction under concentration of H+. To convert fractional pH numbers i.e.7.57 etc.back to concentrations, when necessary, the chemists uses "log" tables.

When using pH units though, even chemists sometimes forget that: 1 pH unit equals a tenfold change in hydrogen ion concentration.

0.1 pH unit equals a 20% change.

Note that the range is not necessarily 0 - 14.
Acids as strong as -0.3 pH and alkalis of 14.5 pH are known.

The relation between pH and "acidity" or "alkalinity" can best be illustrated by the analogy of tanks of water.

pH measures degree or intensity of acidity or alkalinity
"Acidity" or "Alkalinity" analyses determine amounts.

Thus two tanks of similar depth but different sizes give the same pressure (intensity) at the outlet, but hold entirely different amounts of water. Similarly, two different solutions at the same pH can hold entirely different amounts of acidity (or alkalinity). This is dependent on their "buffering power". In water this is provided mainly by the bicarbonate ion HCO_3'.

(strong acid) $H^+ + HCO_3' \longrightarrow H_2CO_3$ (weak acid)

(this can break down further into $H_2O + CO_2$ which escapes)

(strong base) $OH' + HCO_3' \longrightarrow H_2O + CO''$ (weak base)

COAGULATION AND SEDIMENTATION OF WATER

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Many of our waters are unfit for domestic use due to the presence of colour, turbidity, bacteria, and other organisms. In a few cases, sedimentation will settle out the suspended material and produce a satisfactory water. In most cases, coagulation is necessary to obtain satisfactory settling.

COAGULATION

Coagulation is brought about by the addition of chemicals, that in very dilute solution form gelatinous precipitates that have the ability to gather together suspended material and form a floc. For good coagulation it is essential that the coagulant be dispersed throughout the water as rapidly as possible. This may be done either by mechanical agitation or by introducing the chemical into the suction side of a pump. If the best efficiency is to be obtained it is necessary to follow the rapid mix with flocculation. This consists of a period of slow mixing, and in this case the velocity of the water should be just great enough to maintain the floc in suspension. A rolling movement in the water will assist the floc to grow and pick up the suspended material. It is essential once the floc has formed that turbulence and periods of high velocity be kept to a minimum until settling is complete, otherwise the floc may be dispersed and all the benefits of flocculation lost.

COAGULANTS

Salts of aluminum and iron are the coagulants commonly used in water treatment. Filter alum or aluminum sulphate is the chemical usually used. Aluminum chloride, sodium aluminate, ferric sulphate, ferrous sulphate and ferric chloride all have a more limited use. The sulphates are better coagulants than the chlorides, but the chlorides may be used for reason such as cost or because they are more available. In general, aluminum salts have some advantages for coagulation in the lower range of pH and iron salts in the high pH range. There are many variables affecting the use of coagulants, such as, pH, dissolved solids, alkalinity, acidity, temperature, turbulence, etc. It is possible to change some of these variables to obtain optimum conditions.Others have been set by plant design or by nature and have to be accepted.

ALUM

In normal water works operation alum coagulates in a pH range of 5.5 - 7.5. In this range, the alum is only partially hydrolized and precipitates as a hydrated sulphate that forms a dense floc that settles well. In a water softening plant the reaction occurs in a pH range of 10-12, in this case, hydrolysis is almost complete and the floc formed is lighter and consists of almost pure aluminum hydroxide. If the pH is raised beyond 12, aluminum hydroxide goes back into solution.

When water contains high dissolved solids it is usually possible to get satisfactory coagulation over a wide range of pH. In the case of our northern waters that are highly coloured and have a very low dissolved solids content, it is often impossible to obtain a good floc with alum alone. In some cases, it is necessary to adjust pH very closely with sulphuric acid. In other cases where alkalinity is low, it is necessary to increase the alkalinity by the addition of soda ash or lime. Lime is the more economical chemical to use but in some cases lime will not produce a floc and it is necessary to use soda ash. Sodium aluminate can also be used to raise the alkalinity and in some cases a combination of alum and sodium aluminate gives the best results.

In wintertime, low temperatures slow up rate of reaction and at 32°F. it is often impossible to produce a floc with alum alone. The best answer in this case is to use a coagulant aid, and activated silica has proven very effective at low temperatures.

If coagulation with alum results in an aggressive water, it is preferable that pH correction take place after filtration.

When pH is corrected before or during coagulation, it invariably slows the rate of reaction and is also more costly, as the higher pH results in a greater hydrolysis of the alum and requires more alkali to neutralize the liberated acid.

SODIUM ALUMINATE

This chemical is more costly than alum but has some decided advantages where coagulation takes place in the pH range of 10-12, such as in water softening plants. When alum is used in a softening plant, it is necessary to add additional chemicals to react with the sulphuric acid that is set free, but when sodium aluminate is used there is an alkali set free that takes part in the softening reaction and reduces the amount of soda ash required.

As mentioned previously, sodium aluminate is used along with alum in treating soft waters. There is one point to remember when these two coagulations are used together, that they have to be fed separately and the order in which they are added often makes a marked difference in the results obtained. When powdered alum and sodium aluminate are mixed dry they form a sticky mass that will not dissolve and has to be thrown out.

New forms of sodium aluminate are now on the market, that have a lower alkali content than those originally supplied. This type of coagulant has been used with some success, but they usually react in a pH range where coagulation is slow and not too efficient. They have one advantage that the finished water doesn't need pH adjustment to prevent corrosion.

FERRIC SULPHATE

Ferric sulphate is a good coagulant and could be used in most cases in place of alum. It has some advantages in that it reacts over a wider pH range and produces a heavier floc. It also has some disadvantages, in that it is very difficult to put into solution and if coagulation is not complete any iron left in solution will cause staining. It is also more costly than alum in most areas.

FERROUS SULPHATE OR COPPERAS

This chemical is easier to put into solution than ferric sulphate, but it requires to be oxidized when it is used or there will be the problem of residual iron in solution to cause staining. Oxidation, however, is not a great problem as dissolved oxygen in the water will oxidize it quite rapidly or it can be done by chlorination. After oxidation its properties will be similar to ferric sulphate.

COAGULANT AIDS

With some waters and especially under certain conditions such as low temperature, it is impossible to form a satisfactory floc with coagulations alone. It is then necessary to turn to other chemicals that are known as coagulant aids. There are a number of these to choose from, such as, activated silica, sodium aluminate, polyelectrolytes and certain clays.

ACTIVATED SILICA

This coagulant aid is probably the one most used at the present time. In many cases, activated silica makes a most remarkable change in the coagulation and flocculation processes. It widens the useful pH range, forms a floc faster, produces a denser, more stable floc that settles faster, gived better clarification, uses less coagulant for turbidity, gives longer filter runs, and is effective right down to the freezing point. Unfortunately, activated silica does not always produce all these desirable improvements and occasionally produces negative results.

The difficulties with it is that it has to be activated and if a batch process is used, large tanks are necessary as it has to be stored as a dilute solution. If a continuous activator is used it has to be controlled carefully. If a mistake is made, the result is usually a large tank of silica gel that has to be disposed of.

There are many chemicals that can be used to activate the sodium silicate and it is usually possible to select one that will serve a double purpose. For example, if chlorination is being used in the plant it is natural to use ammonium sulphate. In a water softening plant, sodium bicarbonate would be a natural choice. In most plants, chlorine could be used to advantage. There are also many other chemicals to choose from, such as, the strong acids, acid forming chemicals such as the bisulphates, sulphur dioxide and carbon dioxide.

CLAYS

Bentonite and other clays are often useful in coagulating clear coloured waters in which there is no suspended material to act as nuclei for the formation of floc. In this case, the clay acts as nuclei and also builds up a denser floc that has better settling properties.

POLYELECTROLYTES

There is quite a large number of compounds being sold as coagulant aids under the name of polyelectrolytes. Included in this group are starches, esters of cellulose, polymers and gums.

In general, they produce results similar to activated silica and in some specific cases have been superior. However, the finding of our laboratory, to date, is that activated silica is still the best all around coagulation aid that we have tested. In comparing costs, silica also has an advantage.

SODIUM ALUMINATE

This chemical is not as spectacular as activated silica but is certainly worth considering when satisfactory coagulation cannot be obtained with alum. It has the advantage that it doesn't have to be activated and can be fed from most types of feeders. It is necessary to use certain precautions as mentioned earlier.

JAR TESTS

With all the information we have and all the work that has been done in the past, it is still impossible to say which coagulant will be best for a given water. There is still only one way to find out and that is to carry out tests with a jar tester.

A jar tester is simply a multiple stirring device that allows us to (a) compare coagulants under identical conditions, (b) determine optimum dosage for any coagulant, (c) determine the order of adding chemicals to give the best results, (d) decide the kind of mixing that will produce the best floc, (e) determine the length of time to form a floc, (f) estimate the rate of settling to be expected from the floc formed.

In water works where the condition of the raw water changes frequently, a jar tester is a "must" if efficient use of coagulants is to be obtained.

The standard jar test uses a two minute rapid mix followed by a thirty minute slow mix for flocculation. This gives good results for comparing water and coagulants but is not too satisfactory for plant operation. It is necessary to duplicate the rate of mixing and times used in the plant, otherwise the results obtained might be misleading.

SEDIMENTATION

Sedimentation is the settling out of suspended material in a liquid due to the force of gravity. There are several factors that influence the rate of settling. Particles tend to settle at a rate in proportion to their diameter. However, when particles become very fine, the influence of the electric charge carried by the particles is noted and when the force of this charge is greater than the force of gravity the particles are dispersed and will not settle. This is known as a collodial suspension. Specific gravity of the solids also effect the rate of settling,

but as the specific gravity of most natural turbidities is fairly constant, it is not necessary to consider it. However, the density of a floc may vary considerably depending on coagulant used, pH and other factors, and in the settling of coagulated solids the density of the floc can be important. Jar tests will often show that a small dense floc settles much more rapidly than a large fluffy floc. Temperature is also an important factor in settling due to its effect on the viscosity of water.

The purpose of sedimentation is to remove as much of the suspended solids as possible in the time available. To do this, it is necessary to produce a sedimentation basin with the lowest possible rate of flow and a minimum of turbulence.

In designing settling basins, some consideration should be given to sludge removal. Where turbidity is low and coagulant dosage small, occasional dewatering and cleaning of a tank may be satisfactory. Where turbidities are high and high coagulant dosage is required, much of the effective settling time can be lost to sludge storage if some means of sludge removal is not supplied.

WATER FILTRATION

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PROCESS OF FILTRATION

In the remarkable book "The Quest for Pure Water", M.M. Baker quotes a Sanskrit document, the contents of which date back to 2,000 B.C. The quotation is "Impure water --- may be purified by filtration through sand and coarse gravel". It is obvious that for the next 4,000 years such treatment methods constituted an art rather than a science, for in the forward to the same book, Abel Wolman states"--- from the late 1890's rule of thumb has been increasingly replaced by the making and application of the results of scientific research." Rule of thumb has not yet been completely eliminated in either design or operation. However, a considerable amount of research is being conducted currently making it increasingly difficult to keep abreast with all that is being written relative to water treatment methods, plant design, and operation.

Water filtration may be described as the process by which water is separated from suspended matter by passage through a porous substance. In practice, this porous material is usually a layer of sand and anthrafilt. Among filters two general types namely slow and rapid are in use. The rapid filters, in turn are also of two types namely the widely used free surface or gravity type and the pressure type.

In slow sand filtration the water is passed by gravity downward through the sand at low velocity usually at rates ranging

from 2 to 10 USMGD per acre (o.032 to 0.160 USGPM per sq.ft.). Slow sand filtration is not in common use today and therefore will not be discussed in this paper.

In gravity rapid sand filtration, the water is passed by gravity downward through the sand at high velocities usually at rates ranging from 2 to 3 USGPM per sq.ft. (125 to 188 USGPD per acre). Pretreatment with a coagulant is essential in order to remove much of the suspended matter by settling. The rapid sand filter is cleaned by a reverse current of wash water, commonly referred to as backwasking, which expands and scours the sand and carries away the accumulated solids to waste.

Pressure filters are enclosed in tight steel cylinders. Rates of filtration range from 2 to 4 USGPM per sq.ft. The filters are also cleaned by back-washing. Pressure filters are not suitable for large installations due to the limitations in size of units and the impossibility of daily inspection.

PURPOSE OF FILTRATION

The foremost purpose of filtration is to protect the public health. In order to accomplish this, it is necessary to produce water which is free from pathogenic organisms. There is currently a tendency to rely on chlorination to accomplish this. However, there have been instances where chlorination has been known to fail, so it is well to have dependable filters. The degree of pollution of raw water which can be handled by various types of treatment has been developed by H.W. Streeter and is given in the table below.

Monthly Average Coliform Index per 100 ml	Limits of Variability	Treatment Method
50	none	chlorination
5000	Not more than 5000 per 100 ml in more than 20% of monthly samples	Filtration and post chlorination
5000	More than 5000 per 100 ml in more than 20% of monthly samples but not more than 20,000 per 100 ml in more than 5% of monthly samples	Presedimentation prechlorination filtration and post chlorination
more than 5000	none	Prolonged preliminary storage or other reliable measure in addition to pre-chlorination filtration and post chlorination

Raw water quality objectives in the Province of Ontario include an M.F. Coliform Count not greater than 2,400 per 100 ml.

The second purpose of filtration is to produce water which satisfies the consumers. The people who pay for the public water supplies have a right to expect water that is suitably clear, free from taste, odour, and colour.

PRETREATMENT

The quality and efficiency of pretreatment processes have a major influence on filter behaviour and operation. The role of pretreatment has changed greatly in the last few decades. Operators used to apply fairly dirty water to the filters, consequently many of the filters functioned poorly because of the heavy load placed on them. However, the quality of pretreatment has steadily improved. The quality of settled water produced by pretreatment today is frequently better than the quality of filtered water which was produced 30 years ago. Filters are still needed to complete the clarification and bacterial removal processes begun in pretreatment. In addition, filters are essential for guarding against possible upsets that may occur in pretreatment caused by changes in raw water quality or by human failure.

FILTER CAPACITY - GENERAL DESIGN REQUIREMENTS

In most instances, records of past water use are available to serve as a guide in determining design requirements. Such records should provide average daily consumption, maximum day and maximum hour consumption, and should enable the designer to construct mass diagrams of water use for periods of maximum demand. When such information is lacking, the designer must use his judgment and assume water consumption requirements.

The ratio of annual average water use to maximum day and maximum hour use varies from community to community depending on many factors including geographical location, population, character of community, industry, and availability of private supplies.

In general it is good practice to install filters with a total capacity equal to the maximum day demand, and to install filtered water storage equal to the fire and emergency requirements plus the peak hour requirements on a maximum day. This will usually result in reservoir capacity at least equal to 25% of the installed filter capacity.

It is necessary to provide flexibility in operation by allowing for the contingency of having at least one filter out of service repair. This requires that a plant having a capacity of 1.0 mgd must have at least two filters rated at 0.5 mgd. Not less than two filters should be provided for small plants.

COMPONENT PARTS OF A FILTER

Loss of Head

The loss of head measurement is important because it indicates whether or not the filter is operating satisfactorily. The loss of head should rise steadily throughout the filter run. Any sudden drop in loss of head shows a breaking or cracking of the sand bed which might permit unsatisfactorily filtered water to pass through the system. The head loss also indicates when the filter needs to be washed.

At the start of a filter run i.e. the initial head loss varies between one to two feet. It can be stated that the initial head loss increases with an increase in rate of flow and depth of filtering material, and with a decrease in grain size porosity, and water temperature. Comparing anthrafilt media with sand media the former will give a lower initial head loss when all other factors are constant. This is largely caused by the fact that anthrafilt has porosity values 13% to 15% greater than that of sand.

The maximum loss of head should not exceed the thickness of the sand plus the depth of water above the sand. This condition should ensure a positive head at all points in the filter. Normally for a 10 foot filter box the maximum desirable loss of head should not exceed 7 feet. Excessive head losses create a negative head at the bottom of the sand bed creating air binding with a subse= quent reduction in filter capacity.

Rate of Flow Control

The device for controlling rate flow of water through a filter is called the rate flow controller. With normal operation this rate is 2 USGPM per sq. ft. If it were not for the rate of flow controller the filtration rate would not be uniform. Water would go through the filter at a very high rate at the beginning of the run, perhaps not being well filtered. This would tend to quickly pack and clog the filtering material. On the other hand, the flow might be very low near the end of the run. The controller automatically allows the water to pass through the filter at a constant rate. The rate of flow through the filter may be checked as follows:

1. Fill the filter to a marked elevation
2. Close influent valve (Valve A, Figure #1)
3. Open effluent valve (Valve B, Figure #1)
4. Determine the time in minutes necessary to filter the water in the filter down one foot

$$\text{USGPM} = \frac{7.5}{\text{Time in minutes to drain down one foot}} \times \frac{\text{Area of water being measured in sq.ft}}{\text{Filter sand area in sq. ft.}}$$

Underdrain System

The function or purpose of the filter underdrain system is threefold.

1. Support the filter media
2. Collection of the filtered water
3. Uniform distribution of wash water

The design of the filter underdrain system is determined almost entirely by the requirements for uniformly distributing back-wash water. Filter back-wash water flows are normally from 15 to 25 USGPM per sq.ft. or expressed at a rise rate, 24 to 40 inches per minute. These flows are from 7½ to 12½ times the nominal 2 USGPM per sq.ft. filtration rate. Filters which have uniform distribution of wash water and a proper wash water rise rate will require minimum filter bed maintenance and overhaul.

Shifting of the filter gravel bed is caused by high localized wash water velocities. Filter underdrain design innovations are very often an attempt to minimize this cause of gravel shifting.

Filter underdrain systems are usually considered to be of two general types:

(a) Wash water is distributed evenly over the filter by a system of laterals and manifolds having uniformly spaced orifices.

The head loss through the orifices is high compared to the losses in the laterals and manifolds. Perforated cast iron or transite pipe, the Leopold underdrain, the Multicrete underdrain and the Criscrete underdrain are illusative of this general type.

(b) Wash water is applied to the underside of the filter underdrain.

This application is made possible through false bottom construction. The water beneath this false bottom moves with almost negligible velocity and loss of head. The false bottom is porous or punctured with numerous uniformly spaced orofices through which water is distributed upward into the gravel and filter media. The Wheeler underdrain, the Feco-"Fre-Flo" transite filter underdrain, the Aloxite underdrain and the Multi-Plate underdrain are illusative of this type.

Filter Gravel

The filter bed usually consists of 6 layers of gravel but one or more of the coarser layers are eliminated in case one of the patented false bottoms is used. In the case of the Aloxite porous plate underdrain no filter gravel is required and sand is placed directly upon the porous plates. This feature makes filter maintenance and sand replacement relatively simple and economical. However, the use of this plate is limited to waters which have good filterability and are chemically stable. Clogging of the plates under these conditions is negligible and a long time satisfactory service may be expected.

Size limitations of gravel are imposed at one end by the arbitrary value of 2 mm which separates sand from gravel. Size limitations of the coarsest gravel are dictated by the sizes and spacings of the individual openings or orifices in the underdrain system. The depth of any layer obviously cannot be less than the diameter of the largest particle in that layer and should not be less than twice the particle diameter. The AWWA Standard Specifications for Filtering Materials give a minimum layer thickness of two inches. It has been suggested that the gravel should be graded in accordance with the following equation.

$$M = K \log D$$

where M = depth in inches below the material of a given size
K = a constant whose value should be in range of 10 to 14
D = particle diameter in millimeters

The gravel used should consist of hard, rounded, durable particles weighing approximately 100 lbs. per cubic foot. It should be free from flat, thin, or long shaped pieces and washed and screened free from loan, sand, clay, shells, dirt and other foreign material.

Filter Sand

The layer of graded and washed filter sand should be 24 to 30 inches in depth. The sand usually has an effective size ranging from 0.35 to 0.50 mm and a uniformity coefficient of not more than 1.7

Effective size is the theoretical size of sieve (in mm) that will pass 10% of sand.

Uniformity Coefficient =

$$\frac{\text{theoretical size of sieve (in mm) that will pass 60\%}}{\text{theoretical size of sieve (in mm) that will pass 10\%}}$$

There is some difference in opinion whether or not round grains are superior to sharp grains. Sand used for filtration may be obtained from the sea shore, from river beds, from sand banks, or from crushing quartz. It should consist mainly of quartz grains but may also contain hard silicates. Sand is frequently found mixed with clay or other particles which must be removed from it by washing before it can be used in filtration.

From the standpoint of filtration it is desirable to have a sand that will perform as follows:

(a) Prevent any floc passing through the filters.
(b) Hold floc as loosely as possible in order to permit easy washing and prevent the formation of mud deposits.
(c) Hold as large a volume of floc as possible without clogging.

From the standpoint of washing the following characteristics are desirable:

(a) Cleanse itself and be free from adhering floc at the end of wash.
(b) Permit the passage of water at sufficient velocity to remove akk the sediment without losing sand.

Anthrafilt

Anthrafilt, a type of hard coal properly crushed to the desired effective size and uniformity coefficient, is being used successfully as a filter media instead of sand.

Anthrafilt has an average specific gravity of 1.5 as compared to 2.65 for silica sand and crushed quartz. The weights per cubic foot are approximately 55 lbs. and 100 lbs. respectively; thus a ton of anthrafilt will fill almost twice as much filter volume as a ton of sand. Effective sizes up to 0.70 mm. have been used, as measured by sand-rated sieves.

The principle advantages claimed for anthrafilt over sand are as follows:

(a) Because of the lower specific gravity of the anthrafilt only about half the back-washing velocity needed for sand is required for anthrafilt of the same size to produce equal expansion. This results in a considerable saving in wash water.
(b) Anthrafilt of the same effective size as sand has a greater porosity.

Recently, a combination of anthrafilt and sand has been used. A top dressing of 8 to 15 inches of anthrafilt on sand acts as a roughing filter and increases the length of the filter runs.

When such a combination is used, sizes must be carefully chosen in order to maintain segregation of the two media following back-washing.

In attempting to make a choice between sand and anthrafilt one should be influenced by the character of the suspended solids in the applied water. If these solid particles are very small, then reliance must be made on interstitial straining for their removal. In this respect round grains of sand are to be preferred for the removal of finer material.

Wash Water Troughs

Wash water troughs should be set to allow a sand expansion of 50% while still providing several inches of clearance between the expanded sand and the outside bottom of the trough. This requirement results in a through-lip about 30 inches above the top of the sand. Generally, the height from the sand to the overflow edge of the wash water trough should be the same distance the wash water will travel in its upward rise in the filter in one minute of time.

It is very important that the overflow weirs be level and the elevation of each gutter be exactly the same.

The rate of wash may be checked as follows:

1. Filter or draw down water in filter to top of wash water trough.
2. Close wash water drain. (Valve C. Figure #1)
3. Open wash water valve. (Valve D. Figure #1)
4. With wash water valve at normal setting determine the time necessary for wash water to rise one foot in filter.

$$\text{Rise (inches per minute)} = \frac{12}{\text{Time in minutes to rise one foot}}$$

The carrying capacity of lateral gutters is frequently too small for the volume of wash water which must be carried away. Flooding of the wash water troughs represents a loss of efficiency in washing the filter and should be avoided by providing troughs with ample carrying capacity. This frequently requires very large gutters especially when a high velocity wash is used.

FILTER OPERATION

The detailed operation of a gravity rapid sand filter is explained by following operating instructions in the sketch shown on Figure 1.

Filtration Rates

Practice has been quite stable for about 30 years in rapid sand filter design. The experimental work on filtration rates in Chicago carried on in an experimental filtration plant, tested filtration rates up to about 4 USGPM per sq. ft. and established that these were safe to use under certain conditions. For example, the Chicago plant could operate at 4 USGPM per sq.ft. during times of the year when the pretreatment was effective. In the summer time, when the water was warm and the floc was usually strong, it was possible to go to the higher filtration rates. The South District Plant in Chicago was designed on the basis of 3.5 USGPM per sq.ft. in summer and 2 USGPM per sq.ft. in winter.

It is best to run all the filters at the lowest possible rate rather than to turn them on and off to govern plant production. In other words, if a city that needs 10 million gallons per day has a plant with a rated capacity of 20 million gallons per day employing twenty-one million gallon filters, the best procedure would be to reduce the 20 filters to ½ the rate rather than to shut down 10 of the filters. The water quality and the safety factor will improve.

It is evident from the facts that are known about filtration rates and filter beds, that increases in filtration rates do have an adverse effect on water quality. When the filtered water quality is not known, the operator has no business increasing filter rates. Before attempting to increase, there should be clear evidence that adverse results will not occur.

Filter Washing

The mechanics of the washing process involve two phases:

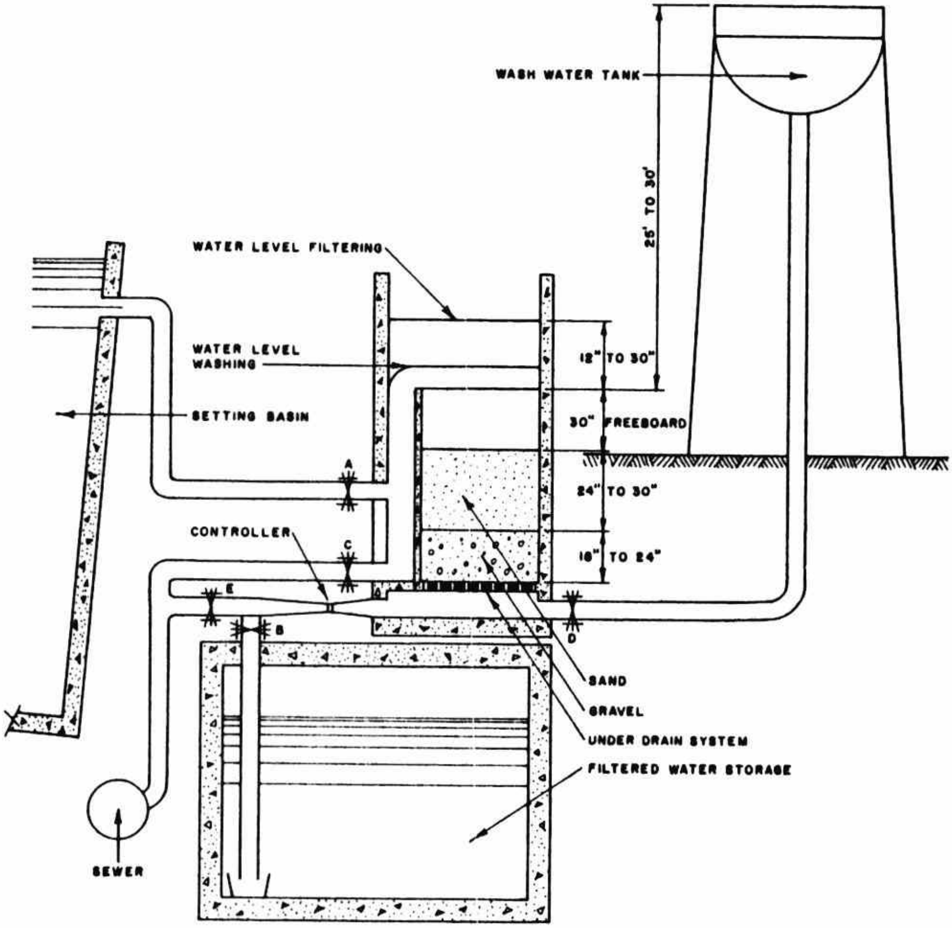
1. A scouring of the dirt from the sand grains.
2. A sluicing away of the suspended dirt to the drain.

Applied water, carrying a high content of turbidity inadequately coagulated in advance, will penetrate deeply into the filter bed and will require a longer period of washing than a properly prepared water. Algae, and in some cases plankton, not removed in advance of filtration will clog filters so quickly that the frequent washing necessary to keep the filters in service seriously reduces the net production of the unit. Similarly, activated carbon in excessive rates of application will penetrate deeply and even pass through filters reducing the effective length of filter runs.

To assist the back-wash, various types of surface wash or agitation have been employed. The stationary surface wash system consists of a grid system placed directly on top of the sand. Small water jets dig into the surface of the sand and loosen it so that when the wash water is applied it breaks through the sand uniformly. The surface wash, left on during back-washing, also scours and cleans the expanded sand. The most recent development in the cleaning of filters is the self propelled revolving agitator (the Palmer Sweep). This agitator is installed just above the normal level of the bed. Water of 50 psi minimum pressure emmitting from nozzles causes the agitator to rotate. This process circulates the filter media during back-washing thus exposing all particles of the media in the bed to the scouring action of the jets.

DIAGRAMMATIC SKETCH SHOWING FILTER OPERATION

FIGURE I



HOW FILTER OPERATES

1. OPEN VALVE A. (THIS ALLOWS WATER FROM SETTLING BASIN TO FLOW TO FILTER.)
2. OPEN VALVE B. (THIS ALLOWS WATER TO FLOW THROUGH FILTER TO FILTERED WATER STORAGE. DURING FILTER OPERATION ALL OTHER VALVES ARE CLOSED.)

HOW FILTER IS WASHED

1. CLOSE VALVE A.
2. CLOSE VALVE B WHEN WATER IN FILTER FILTERS DOWN TO TOP OF OVERFLOW.
3. OPEN VALVES C AND D. (THIS ALLOWS WATER FROM WASH WATER TANK TO FLOW UP THROUGH THE GRAVEL AND SAND, LOOSENING UP THE SAND AND WASHING THE ACCUMULATED DIRT FROM THE SURFACE OF THE SAND, OUT OF THE FILTER, AND INTO THE SEWER.)

HOW TO FILTER TO WASTE

1. OPEN VALVES A AND E. ALL OTHER VALVES CLOSED. WATER IS SOMETIMES FILTERED TO WASTE FROM A FEW MINUTES AFTER FILTER HAS BEEN WASHED IN ORDER TO CONDITION THE FILTER BEFORE IT IS PUT INTO SERVICE.

CHLORINATION

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The basic lecture on chlorination will review the subject under the following headings:

Need for Disinfection
Forms of Chlorination
Chlorine Residual Requirements
Equipment Requirements
Emergency Operation

Future courses will present the theory of chlorination; review the use of chlorine for taste and odor control, and distribution system protection; and present a review of the application of chlorination procedures to specific type plants.

NEED FOR DISINFECTION

The chlorination of public water supplies represents the most important process used in the production of potable water. Secondly, an important reason for chlorination is to provide effective disinfection. Disinfection refers to the reduction of the bacterial population to a safe level, as contrasted to sterilization, which refers to the total destruction of bacterial population.

The object of disinfection is to kill disease-producing organisms which may have gained entrance into a water supply. The bacteria involved are primary those causing intestinal

diseases such as typhoid, the paratyphoids, and dysenteries; most other harmful bacteria are not considered to be spread by impure waters. Besides bacteria, viruses are now being given consideration. It is now believed the virus which causes Infectious Hepatitis can be water transmitted. In the same regard, the poliomyelitis virus may also be of importance.

FORMS OF CHLORINATION

Other disinfectants have been used such as ozone, ultraviolet radiation, bromides, silver, etc., but with few exceptions, chlorine is the main chemical employed. The chlorine is obtained in the form of a gas or one of several compounds such as chloride of lime, sodium and calcium hypochlorites, and sodium chlorite.

Gas Chlorination

Under conditions of normal temperature and pressure, chlorine exists as a gas. However, it is compressed to a liquid and supplied in steel cylinders of 150 and 2,000 pounds capacity. It is also supplied in 16, 30 and 55 ton tank cars.

Essentially, gas chlorinators consists of various combinations of pressure reducing values accentuated by mechanical diaphrams, or hydraulically operated floats,orifices or other types of meters for measuring the rate of flow of the chlorine gas after it has been reduced to a uniform low pressure. Secondly the measured gas is mixed with water before discharge to the water under treatment.

Manual or Standard Chlorinator

Satisfactory for use where constant flow rates are encountered. Off and on operation can be provided with this type of machine.

Semi-Automatic Chlorination

A semi-automatic chlorinator is equipped with proportional control activated from a flow metering device. Feed is varied in proportion to flow changes.

Fully Automatic Chlorinator

A fully automatic chlorinator is equipped with two

guidance controls. A flow meter provides immediate changes in feed control while a chlorine residual recorder provides a final correction.

To ensure continuous operation, the chlorination programme is controlled by routine residual testing and the use of weigh scales to ascertain the chlorine consumption and the chlorine remaining in the cylinder. The daily records kept at the plant should indicate the following:

1. chlorine residuals
2. chlorinator setting
3. weight scale readings
4. chlorine used in 24 hr.period
5. water pumpage, and
6. the chlorine feed rate in p.p.m.

Special notes should be kept on chlorine orders and the dates of changing cylinders. The records collected should be summarized on a monthly and yearly basis.

One 150# cylinder should be connected to the chlorinator for each 35 pounds of chlorine required per day. To prevent condensation, the cylinder should be kept colder than the chlorinator or long gas lines.

Hypochlorination

Sodium hypochlorite, obtained in a liquid form, and calcium hypochlorite purchased in the powder form are both used for disinfection purposes.

Sodium hypochlorite solution is available under various trade names. These solutions vary in strength between five and 10 percent by weight and are reasonably stable when stored in cool, dark places.

Calcium hypochlorite, also known as chloride of lime, is also used at times. As this compound is relatively unstable, it should be purchased in small quantities. The commercial, products ordinarily contain 25 to 37 percent available chlorine by weight. However, there are several commercial compounds containing 65 to 70 percent available chlorine by weight. These latter compounds are more stable, but more eepensive.

Hypochlorite compounds and solutions are reduced with water to the required feed strength. The material in the

chlorinator may restrict the solution strength to one percent. Otherwise the dilution should enable an adequate residual with a mid-point setting on the chlorinator control. When the solutions must be made from a powder two feed crocks are necessary. One crock is used to mix and settle the solution before it is transferred to the final feed crock. In all cases the use of two tablespoons full of calgon with each crock of solution is advised to minimize scaling.

The hypochlorinator itself should be of the piston or diaphgram type of positive displacement pump. When variable flows are encountered a proportional feed hypochlorinator is required.

Accurate records should be kept of chlorine consumption. The residual determinations are performed on a routine basis and recorded in a log.

Calculation of Chlorine Dosage

Where: a = solution strength,
b = solution used from crock, and
c = water pumped;

the chlorine dosage in p.p.m.

$$= \frac{a \times b \times 10,000}{c}$$

e.g. a = 0.5%
b = 8 imperial gallons
c = 20,000 imperial gallons

$$\text{chlorine dosage} = \frac{0.5 \times 8 \times 10,000}{20,000} = 2.0 \text{ p.p.m.}$$

CHLORINE RESIDUAL REQUIREMENTS

General

The minimum chlorine residual required by the Ontario Water Resources Commission are ourlined in the appended Technical Bulletin W-63-1. Generally the minimum requirement consists of a 0,5 p.p.m. chlorine residual, free or combined, when the contact period between the water and the chlorine is less than two hours. When pre and post chlorination is performed in a complete treatment plant the minimum residual requirement is 0.2 p.p.m. free or combined. Protected water supplies such

as springs or wells may also qualify under the reduced standard. Depending on raw water quality and other factors higher chlorine residuals may be specified. Also, free residual chlorination is to be encouraged.

Testing Frequency

The chlorine residual test must be performed frequently. This is necessary to detect equipment failures and changing chlorine demand. When 24 hour operator control is provided the test should ne performed at least every four hours with more frequent testing being required when the chlorine demand fluctuates. When the raw water quality is excellent and chlorination is not critical the frequency of testing may be reduced to twice per day. Spring and well sources of water supply could meet the reduced standards criteria.

Testing Procedures

For routine chlorine residual testing these procedures may be followed:

1. Draw sample of chlorinated water. The tap should be kept running continuously or for a few minutes before taking the sample.
2 Allow sample to stand for 15 minutes to simulate the required minimum contact period.
3. Use 0.5 ml of orthotolidine (O.T.) reagent in 10 ml cells, 0.75 in 15 ml cells, and 5 ml in 100 ml tubes. Place reagent in testing tube; add sample to required volume; and mix. When the temperature of the sample is less than 68°F bring it to that temperature quickly after mixing with the O.T.
4. A colour comparison is made when the maximum colour develops.
5. The test results are recorded in the plant records and the necessary alteration is made to the chlorine application rate.

The above procedure is satisfactory for determing the total available chlorine residual. When the free residual is required the sample must be near 32°F when the O.T. is added and the colour comparison is made immediately. The orthotolidene-arsenite (O.T.A.) test can also be used to determine the free available chlorine residual.

When more complex chlorination programmes are undertaken the amperometic titration method of measuring chlorine residuals should be considered.

CHLORINATION EQUIPMENT

Chlorine Feed Equipment

Dependable feed equipment, either of the gas feed or solution feed type, should be used for adding chlorine. Installations having chlorination as an essential treatment for assuring the safety of supplies should have duplicate chlorination facilities when operating conditions do not conveniently permit repair of the chlorinator during off-pumping periods.

Spare Chlorinator Parts

Spare parts consisting of at least the commonly expendable parts such as glassware, rubber fittings, hose clamps, and gaskets, should be provided for effecting emergency repairs.

Location Equipment and Cylinders

Space provided for chlorination equipment should allow easy access to the equipment for repair and maintenance. Where gas-feed chlorination is to be used, chlorinators and cylinders should be located so that they can be serviced in the event of gas escape; unless natural ventilation to the outside atmosphere can be made available quickly, facilities for providing mechanical forced-air centilation should be installed; blower vents should have their intakes at or near floor level. Operating gas-feed equipment should be located in rooms free from excessive heat.

Chlorine Gas Mask

For minor leaks a canister respirator may be satisfactory for operator protection. Using this equipment the operator must be aware of its limitation as to gas concentrations and mask fitting.

Large plants should be equipped with an air pack type unit which supplies bottles air under a positive pressure. When a good mask fit is assured a demand type valve may be used on the air pack unit. Smaller plants should make arrangements with the local fire department for the loan of proper equipment during emergencies.

Weighing Scales

Where gas feed chlorinators are employed, one set of corrosion resistant scales should be provided for each chlorinator.

Residual Chlorine Testing Kit

A chlorine comparator testing kit utilizing permanent colour standards or disks should be provided. The comparator range should be from 0 to 2.0 p.p.m. Lesser ranges may be specified if a complete treatment plant is involved and a nesslerizer is available.

When free residual chlorination is advised an amperometric titration unit may be recommended.

EMERGENCY OPERATION

Except where chlorine is used for H_2S removal or iron bacteria control on a safe well source of supply continuous chlorination must be provided. With this requirement in mind each water works system should develop a standby operating procedure. The procedure when developed should be posted in a prominent location in the plant and all operators should be made aware of information thus provided.

Large Plants

Larger water works will require both a standby chlorinator and a store of parts. Also, one of the operators must be capable of making minor adjustments to the chlorinators. The standby machine is operated at least once a week to prevent packing problems. When two similar chlorinators are available alternate operation may be advised.

The emergency information should include:

1. the order to stop pumping water if chlorination is not being provided;
2. the name and telephone number of the service organization, the supervisory authority, the medical officer of health, the liquid chlorine suppliers, and the local fire department; and
3. depending on the installation, other procedures will be required.

Besides the instruction indicated above, each operator should be fully trained to carry out emergency procedures.

Small Water Plants

For smaller installations the emergency information is similar to that detailed for the large water works. However, a second standby chlorinator may not be necessary if hypochlorites can be drip or batch fed to intake wells or on line storage

facilities. The operating instructions should indicate where additional Javex and HTH can be purchased locally and a permanent supply of HTH should be kept in a cool dry location at the plant. Each plant will require a different procedure and an effort should be made to maintain a 1.0 p.p.m. chlorine residual during the emergency.

GENERAL

If at any time it is found that raw inadequately chlorinated water has been directed to the distribution system, except where chlorination is for iron or H_2S control only, the medical officer of health and the provincial regulation authority should be notified immediately. In the interm period the chlorine dosage should be increased to provide a 0.5 to 1.0 p.p.m. chlorine residuals at distant hydrants and in certain instances a boil water order should be issued to the public by radio and daily paper.

ONTARIO WATER RESOURCES COMMISSION

Sanitary Engineering

Water Supply Chlorination Policy

Group I - (a) For complete water treatment plants which effect both pre and post chlorination: or

(b) where a minimum of two hours retention is obtained before distribution and after the application of chlorine; in intake wells, pipe lines, or maintained storage of any type: or

(c) for ground or protected surface water supplies: or

(d) where free residual chlorination is practiced:

the minimum residual shall be 0.2 ppm.

Group II - For water supplies not covered under group I

the minimum chlorine residual shall be 0.5 ppm.

Ground Water - When ground water sources are free from possible contamination and are proven to be bacteriologically safe they may be exempted from chlorination.

AS INDIVIDUAL CIRCUMSTANCES DEMAND THE MINIMUM REQUIREMENTS MAY BE INCREASED OR MODIFIED.

FREE RESIDUAL CHLORINATION IS TO BE ENCOURAGED AND MAY BE MADE MANDATORY IN CERTAIN INSTANCES.

A HIGH COMBINED OR A FREE RESIDUAL IS NOT A SATISFACTORY SUBSTITUTE FOR ADEQUATE TREATMENT FACILITIES. HOWEVER, UNTIL SUCH TIME AS FINANCES PERMIT THE INSTALLATION OF ADEQUATE TREATMENT WORKS EXTRA PROTECTION MAY BE AFFORDED BY INCREASING THE RESIDUAL.

TEST PROCEDURE

1. COLLECT SAMPLE OF PLANT EFFLUENT OR IN THE CASE OF I (B) AFTER THE REQUIRED CONTACT PERIOD IF A PIPE LINE IS INVOLVED.
2. RETAIN SAMPLE FOR 15 MINUTES.
3. PERFORM CHLORINE RESIDUAL DETERMINATION.

STORAGE OF CHLORINE AND OTHER WATER WORKS CHEMICALS

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A multitude of chemicals are available for water treatment applications depending of course upon the purpose or desired results of treatment. Disinfection of a water supply will require the use of chlorine, chlorine dioxide or some other disinfectant; coagulation of water may involve the use of aluminum sulphate, sodium aluminate, ferric sulphate, activated silica and lime; water softening will require lime and soda ash possibly; while taste and odour control may use activated carbon, chlorine, chlorine dioxide and other chemicals. Our study will be limited to the handling and storage of chlorine and its related compounds, alum, lime, activated carbon and fluorides. These particular chemicals which cover the gamut of waterworks chemical treatment usually present the most difficult storage and handling problems.

Appreciation of the reasons why specific chemicals are handled in certain ways requires that operating personnel become well acquainted with the physical and chemical characteristics of these chemicals.

Significant Characteristics

1. Chlorine

Chlorine gas has replaced many chlorine compounds as a more economic and effective means of water disinfection. Its availability in readily handled steel cylinders has made the purchase of chlorine gas more attractive. Hypochlorites are used for particular situations such as emergency applications and in small water works systems.

TABLE I
(a) Chlorine Gas and Hypochlorites

Characteristic	Chlorine Gas	Calcium Hypochlorite	Sodium Hypochlorite
Chemical Name of Formula	Chlorine Cl_2	Calcium Hypochlorite Ca (OCl) 2.4^{H}20	Sodium Hypochlorite NaOCl
Common or Trade Name	chlorine gas liquid chlorine	lime bleach "HTH", "Perchloron" "Pittchlor"	soda bleach javex
Physical State	liquified gas under pressure	solid granule or powder	liquid
colour:	clear, amber liquid yellow-green gas	white	clear, light yellow
odour:	sharp, pungent	slightly chlorinous	chlorinous
	1 volume liquid chlorine = 456.8 volumes of gaseous chlorine 1 pound liquid chlorine = 4.98 cubic feet gaseous chlorine		
density:	liquid form - 91.6 lb. per cubic feet gaseous form - 0.2007 lb. per cubic feet (NTP) gaseous form of chlorine is 2½ times heavier than air		
Reactions with water	aqueous solution saturated with chlorine gas (Cl_2) will form crystalline chlorine hydrate ($Cl_2 8H_2O$) below 49^{o} Fah.	**same as chlorine gas**	completely **miscible** in water

Table 1 continued ....

Characteristic	Chlorine Gas	Calcium Hypochlorite	Sodium Hypochlorite
	At higher temperatures hypochlorous acid formed. Chlorine hydrate formed when liquid chlorine added to water. In dilute solutions, hydrochloric and hypochlorous acids are found - readily soluble.		
Corrosive Qualities	when dry - no reaction with metal. when wet - reacts with most metals.	corrosive in solution	corrosive
Stability	non-flammable; non-explosive in air. Will support combustion of certain powdered metals (antimony, copper, phosphorous) moist or dry chlorine attacks mercury.	fairly stable	will deteriorate more rapidly than calcium hypochlorite - particularly on exposure to light and air

Table 1 continued.....

Characteristic	Chlorine Gas	Calcium Hypochlorite	Sodium Hypochlorite
Shipping Containers	10, 100, 150 lb. cylinders ton containers 16, 30 and 55 ton capacity tank cars.	5 lb. cans 100, 300, 800 lb. drums	5, 13, gal. carboys 1300-2000 gallon tank trucks
Commercial Strength	99.8% Cl_2	70%	12-15%

(b) Bleaching Powder (Chloride of Lime)

These powders contain about 25-35 per cent available chlorine. The remainder is slaked lime. Loss of strength, as available chlorine, is rapid once the container is opened and the contents exposed to air. Chloride of lime dissolves with difficulty and leaves a slurry of slaked lime in the pot.

2. Alum, Lime and Activated Carbon

These three chemicals are grouped together at this point for convenience.

TABLE II
Alum, Lime and Activated Carbon

Characteristics	Alum	Lime	Activated Carbon
Chemical Name & formula	aluminum sulphate $Al_2SO4)_3.14H_2O$	calcium oxide CaO	activated carbon C
Common or Trade Name	alum, filter alum, sulphate of alumina	burnt lime chemical lime quick lime unslaked lime	"Aqua Nuchar" "Hydrodarco" "Norite"
Physical state (available forms)	solid - (powder (granule (lump or liquid (syrup)	solid - lump pebble granule	solid - granule powder abt.99% passes # 200 mesh sieve
- colour	ivory	white when pure	black
Freezing Point	liquid form as shipped abt. 10^{o}Fah.		
Weight per cu. ft.	65# (ground)	lump lime 55# slaked lime 38#	14#
Reaction with water	very soluble. syrup or liquid - acid reaction solid - basic as packaged	chem.lime reacts with water to produce slaked lime at ordinary temps. Slaked lime only slightly soluble in water.	insoluble - (used in suspension)

Table II continued....

Characteristics	Alum	Lime	Activated Carbon
Corrosive Qualities	pH of liquid as shipped - 2.3 pH of 1% solution - 3.4 when dry - not corrosive when wet - very corrosive	not corrosive pH of saturated solution 12.4	-
Stability	Stable	Chemical lime reverts to slaked lime in moist atmosphere	Stable
Shipping Containers	100-200# bags 300-400# barrels bulk carloads	50# bags 100# barrels bulk carloads	bags, bulk
Commercial Strength	solid 15-22% Al_2O_3 (aluminum oxide) liquid 8.3% Al_2O_3 equivalent to 48.8% dry aluminum sulphate	75-99% CaO	-

Activated Carbon - Phenomenon of Adsorption

The principle of use of activated carbon is the capacity of the chemical to exhibit the property of adsorption. This is considered to be the phenomenon of concentrating certain substances, in this case odorous organic compounds at the exposed surfaces of the solid. It is this property which is of significance in the treatment unit.

Activated carbon is made by the conversion of the raw material wood to char by carbonization at temperatures below 500 C. The char is then activated by a slow burning operation under closely controlled conditions at temperatures from 800^{o} Cent. upward.

3. Fluorides

Reference should be made to Table III.

It is noted, with respect to the commercial strength of these compounds, that the actual available fluoride amounts to much less than the figure given for Commercial strength. About 40 per cent of the sodium fluoride and about 60 per cent of the sodium silico fluoride is present as available fluoride.

TABLE III
Flourides

Characteristic	Sodium Fluoride	Sod. Silico Fluoride	Hydro Fluosilicic Acid
Chemical Name	as above	as above	as above
Chemical Formula	NaF	Na_2SiF_6	H_2SiF_6
Common Name or Trade Name	fluoride	as above	fluosilicic acid
Physical State (available forms)	crystalline Solid - powder	solid - powder	liquid
- colour	nile blue or white	nile blue or yellowish white	-
Reaction with water	limited solubility	less soluble than NaF	in solution
Corrosive Qualities	pH of 4% solution 6.6 slightly corrosive	pH of 1% solution 3.5 corrosive	corrosive
Stability	storage of large quantities of the solid form tends to result in moisture pick-up & resultant caking.		
Shipping	bags, barrels, fibre drums, kegs	bags, barrels, fibre drums	rubber-lined drums
Commercial Strength	90-95% NaF	99% Na_2SiF_6	abt. 35%

With this background of the significant characteristics of the chemicals under study, attention will now be given to matters of more practical concern to the plant operator. The following topics will be discussed:

Physiological or Health Hazards Involved.

In-plant handling, including inventory and the efficient transport of these chemicals from receiving to storage and application. The dependable and accurate application of these chemicals will be dealt with in other course lectures.

Physiological Considerations

(a) Chlorine as a gas

Liquid chlorine is classified as a non-flammable compressed gas. The gas is extremely irritating to the membranes in the nose, throat and lungs in concentrations greater than 15 p.p.m. Irritation of the skin and eyes results under higher concentrations as well as coughing and difficult breathing. In prolonged exposures to the gas, retching and vomiting followed by difficult breathing are symptoms. Death can occur from apparent suffocation where breathing difficulties are extreme.

Due to its greater weight than air, chlorine seeks the lowest level in a room. When escaping from a chlorine poisoned atmosphere, it is important to remain above the heavier layers of gas.

First aid procedure which is somewhat beyond this study has been recommended by the Joint Committee Report on the Recommended Procedures in the Use of Chlorine at Water and Sewage Plants (Jour. AWWA, Oct. 1953). Where chlorine gas is used at a plant, it behooves the operator to make himself aware of safety and first aid procedures.

(b) Chlorine in solution

Whether chlorine be in solution as a dissolved gas or in the form of a dissolved solid, the resultant solution is quite acid and will cause acid burns and irritation of the skin. Where clothing has been splashed by a solution of chlorine, the affected clothing should be removed and the skin washed with copious volumes of water.

(c) Alum

As a salt of a strong acid, alum in solution forms an acid pH. Contamination of one's clothes or skin should be washed with water as described previously.

(d) Lime and Activated Carbon

Little hazard is involved in handling these chemicals. Fine dust may cause injury to the eye.

(e) Fluorides

All fluoride compounds whether powdered or liquid are poisonous in all but minute concentrations. When properly handled and stored at a plant fluorides are not dangerous.

Inventory

Closely related to the storage of chlorine is the provision of ample but practical inventories of chlorine. Obviously the size or magnitude of a chlorine inventory will determine the storage requirements for the chemical. It is emphasized that chemicals inventory, especially in the case of chlorine, must be adequate to maintain water quality protection at all times.

Some factors that bear on the problem of inventory are:

(1) Normal length of time required for delivery from the shipping point to the point of use.

(2) The amount of chlorine used per day during periods of high demand for water.

(3) Emergencies which interrupt chlorine deliveries.

The Joint-Committee on chlorine supply which was established in May 1951, has defined inventory of chlorine as applied to water treatment. These definitions are presented here:

(a) Critical Inventory - The number of unconnected (full) chlorine units or containers equal to the number of units normally connected and in service.

A plant is considered to be in emergency operation with an inventory of this nature.

(b) Working Inventory - That inventory which represents a reasonably ample supply to assure continuity of treatment. It should approximate:

(i) a duplication of the connected chlorine units (critical inventory); plus

(ii) a chlorine reserve equivalent to the length of time required for delivery; plus

(iii) a reserve for such occurrences as strikes; transportation interruptions etc. usually equivalent to a 15-day supply. This will vary from plant to plant and must be determined for each individual plant.

(c) Maximum Inventory - That inventory equivalent to a 60-day supply of chlorine at the plant at the normal rate of use. This should only be regarded as a temporary type of inventory since heavy stocks of chlorine tend to tie up an unnecessary number of shipping containers.

TABLE IV

Recommended Chlorine Inventories at Water and Sewage Plants*
Joint-Committee Report

Avg Amount Chlorine Used per Day - lb.	Critical Chlorine Inventory None of Which is in Use ≠	Working Chlorine Inventory None of Which is in Use	Max. Chlorine Inventory None of Which is in Use
	150-lb. Cylinders		
0.5	1	1	2
2.0	1	1	2
5.0	1	1	3
10.0	1	3	4 ‖
20.0	1	4-5 §	8 ‖
50.0	2-3	8-12 §	20 ‖
100.0	3-5	16-24 §	40 ‖
200.0	6-8	30-47 §	80 ‖
	Ton Containers		
300.0	1	4-6 §	9 ‖ #
500.0	2	8-10 §	15 ‖ #
1,000.0 ‡	2-4	12-18 §	30 ‖
2,000.0 ‡	4-6	22-35 §	60 ‖

* 100-lb. cylinders are available. Where they are used instead of the 150-lb. cylinders, the net weight of chlorine in inventory should substantially agree with that shown in the table.

† This column also represents the number of cylinders or containers usually in service. Local conditions could affect these figures materially. Irrespective of the number of units in service, the principle as expressed in the definition of critical inventory should still apply.

‡ Users of 1 ton or more of chlorine per day should consider the use of single-unit tank cars.

§ The smaller of the two numbers represents the working inventory where deliveries require two days. The larger figure represents the working inventory where deliveries take 15 days.

¶ These figures roughly represent 60 days of chlorine inventory.

Maximum inventories listed for these categories are for plants receiving chlorine delivery by truck. For plants receiving chlorine delivery by railroad car (fifteen 1-ton containers) the maximum inventories should be 19 and 23 ton containers, respectively, for plants using 300 and 500 lb. per day.

TABLE V

Recommended Uses of Cylinder or Ton Containers

Total Consumption per 24 hr. lb.	Max. Rate of Withdrawal per 24 hr. lb.	Recommendation	Remarks
100	100	3 cylinders in use (possibly 6 connected)	
100	200	5 cylinders in use (possibly 8 connected)	
200	200	5 cylinders in use (possibly 8-10 connected)	ton containers may be justified*
200	300	ton containers /	1 carload would provide 150 days' storage*
300 or more	300 or more	ton containers /	1 carload would provide 100 days' storage at plants with minimum (300 lb. per day) rate of use

* Delivered by truck, carload lot delivery not usually justified.

/ Some changes in this schedule may be required for seasonal users of chlorine.

In Plant Handling

Unloading Chemicals

For large plants, adequate provision for handling materials upon arrival is important. Where a railroad siding is available, the transfer of carload shipments either by bulk or package to storage may be facilitated by:

(i) arrangements of bins whereby bulk shipments can be shovelled directly into them.

(ii) air conveyors.

(iii) bucket elevators.

With respect to the regulations and specifications concerning the handling and storage of chlorine, the following regulatory bodies are active:

In Canada - Board of Transport Commissioners for Canada - BTCC

IN U.S.A. - Interstate Commerce Commission - I.C.C.

The Joint-Committee presented some general recommendations in respect to the safer use and handling of chlorine and some of these are presented here:

(a) Use reliable men in handling chlorine. They should become familiar with BTCC regulations and specifications.

(b) Adequate room ventilation is required both in rooms where chlorine is stored and applied. Where mechanical ventilation is required (where gas tight rooms are employed) provision must be made to change the air twice every minute.

- Exhaust duct ports should be at floor level, and ducts should terminate in locations where sufficient atmospheric dilution is available for the protection of both personnel and property.

- Air inlets at opposite sides of the room to the exhaust ports.

- Air temperature should not adversely affect the equipment.

- Do not store chlorine containers near elevators, gangways or ventilation systems.

(c) Approved gas-masks should be provided and personnel trained in the use and maintenance of the masks.

(d) Testing for chlorine leaks - Use a stick with an end covered with cloth, soak in ammonia water and probe for suggested leaks. A white cloud of ammonium chloride will indicate the presence of chlorine gas.

(e) Due to its corrosive nature when wet, the gas should be handled in materials such as glass, rubber and silver.

<u>Caution</u>: Never use water on a leak because the resulting corrosion will make the leak worse. When leaks do arise, corrective action is required immediately.

(f) Cylinders or containers should be stored at a moderate temperature. The liquid phase of a full container occupies 88 per cent of the cylinder volume at 68^{o} Fahrenheit. Containers connected to a common header should be kept at the same temperature. Otherwise chlorine could transfer from a warm cylinder to a cooler one and possibly overfill the cylinder. Flame or direct heat should never be applied to a container. The fusible plugs will soften at a temperature between $158\text{-}165^{o}F.$, thus releasing the pressure and preventing container rupture in case of fire or other exposure to high temperature. Never store near turpentine, hydrocarbons or other flammable materials.

(g) Avoid dropping or bumping containers. They should be fastened securely to prevent tipping or rolling. Store cylinders in an upright position and ton containers on their sides above the floor on suitable supports.

(h) Valve protection hoods on containers should always be kept in place except when being emptied. Do not hoist cylinders by the hood.

(i) Keep valves of cylinders and ton containers closed at all times when not in service.

(j) Store full and empty containers in different places to avoid confusion. Tagging is recommended by the suppliers.

(k) Use containers in the order in which they are received. Place on a scale when in use so that the operator may know at all times the amount of chlorine in the container.

(l) Use only approved fittings for connecting containers. Never use pipe fittings on chlorine valves.

Other Chemicals

Hypochlorites in powder form are readily transported and applied within the plant. All hypochlorites when in solution are quite corrosive and handling necessitates the use of corrosion resistant materials. Wood, ceramic, glass, plastic and rubber lined containers and conveyors are used.

The most widely used chemical, in water treatment practice, other than chlorine, alum, is available in both the solid and liquid state. In the past, and to a large extent today, dry crystalline alum has been used as an economical and easily stored coagulant. Only the larger water works plants, where alum is used in any quantity, can consider the use of liquid alum. These plants are usually located within truck hauling distance of the alum producer.

Alum in solution may exhibit either an acid or alkaline pH, and must be handled accordingly. Corrosion resistant materials such as lead, rubber, plastics and stainless steel are used. Pumps and valves when constructed of nickel base alloy are satisfactory. Storage tanks may be of wood, concrete or steel - all lead-lined. Rubber-lined steel and cyprus wood tanks, unlined, are in use. Storage tanks in northern climates should be indoors.

Since alum has a moderately high freezing point, care must be taken in unloading bulk carriers where the liquid has cooled. Clogging of piping with crystallized alum will hamper unloading.

Lime is used for water softening either as quicklime or slaked lime. The choice of form depends on economic factors. Hydrated lime is used more generally in smaller plants because it keeps better in storage and does not require slaking equipment. Quicklime, however, costs less per ton of available CaO and therefore is economical for use in large plants.

Lime should be stored in a dust tight area.

The use of powdered activated carbon requires isolated storage and feeding plant to minimize the dirty conditions associated with its handling. Special discharge boxes are used wherein a bag of the material may be opened and emptied to control the spread of the black dust.

The storage location should be selected and designed to avoid the risk of fire. Locations safe from excessive heat, flame or sparks are required. Should the carbon catch fire, extinguish the fire with a fine spray of water or a foam type extinguisher to prevent scattering of the burning carbon dust. Elevation of the bags of carbon on a steel framework that will permit the circulation of air around the bag will reduce any tendency for heat to build-up in the package. This will also protect the material from becoming wet. Wetting will not destroy the activity of carbon, however, trouble may be experienced with feeding due to arching in the hopper.

The air should be devoid of chlorine or gas vapours, otherwise these will be adsorbed by the carbon, decreasing its efficiency.

Fluorides

The following precautions are given concerning the handling and storage of powdered fluorides.

(i) The operator should follow all instructions as provided by the manufacturer.

(ii) Wear the recommended protective clothing, eg. gloves, masks or other respiratory devices, goggles, etc.

(iii) Breathing or swallowing fluoride dust must be avoided.

(iv) Wash thoroughly after handling fluorides and clean up spillage.

The pneumatic emptying and conveying of powdered fluorides has greatly eliminated the dust hazards. The conveyor nozzle is inserted in the container by this method and the material is drawn upward by the creation of a vacuum. Suitable exhaust fans should be employed to remove any residual dust in the atmosphere.

Due to the corrosive nature of solution of either sodium silico fluoride or hydro-fluosilicic acid, these must be handled in corrosion-resistant materials such as rubber or plastic, stainless steel, monel metal, porcelain or tar-coated wood.

It is suggested that fluoride storage and feeding equipment be located in separate areas other than chemical storage and feeders. A separate dust-tight room is recommended.

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DISTRIBUTION SYSTEM MAINTENANCE

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INTRODUCTION

Maintenance comprises those operations which serve to keep a system functioning properly. Repairs, on the other hand, are those steps taken ro replace broken or worn parts of the system. Since these two terms are not given the same meaning by everyone, we shall use the term preventive maintenance to mean ways of keeping a system functioning without costly breakdown.

MAIN LINES

Adequate maintenance of any part of any system requires a supply of proper tools, equipment and repair parts. The tool supply should include pumps, cutters, wrenches of all types, air tools, caulking tools and various kinds of small hand tools. When a large line is cut or broken, the best available pump should be used. Caulking tools are needed when lead joint pipe is used in the system. Air tools save valuable time when it is necessary to cut through a paved road. Various types of pipe cutters may be used but when it is necessary to remove a section of pipe it is handy to use a cutter such as the Strickler ratchet cutter which removes about 1/8" of the pipe allowing easy removal. It also helps to eliminate the danger of breaking the pipe which is to remain in sercice. In making any cuts in a pipe it is important to cut only as much as required and if possible to make all cuts square which enables better joints where fittings are to be installed.

Various other types of equipment are used which help to save time and money during repairs. There are for example, two way radios which cut down the number of men required to maintain the system; leak detectors which have the obvious advantage; pipe locators of all kinds are used for spotting underground pipes and where there are many underground lines a special wireless electric locator is used; a valve box locator, which is no more than an inverted compass which will pick up almost any metal such as valve boxes, meter boxes or sewer manholes and is especially handy in case of emergency.

A good supply of repair parts is important as any repair job can be costly if it has to be patched up until the parts are available.

The maintenance of main lines has become one of the biggest jobs. The reason for this is the street reconstruction which requires the pipe to be relocated, lowered or offset.

When lowering a line it should be let down slowly and the offset in each joint kept the same. Care should be taken that the deflection in each joint not be permitted beyond the maximum limit. As an example, when lowering an eighteen foot length of eight inch diameter cast iron mechanical joint, never let each such length of pipe deflect more than 20". The maximum allowable deflection for any pipe or joint size can be found in the manufactures hand book. If the pipe being lowered had lead joints it is necessary to recaulk each joint.

If an offset in a large line is to be made with bends, it is recommended that straps be used to hold the bends in place. All bends must be firmly blocked before the water is turned on as any pressure surge on an unsupported bend can take it right out. An offset is made by joining two 1/8 bends together.

Many kinds of fittings and repair parts are used in line repairs and a few of them are listed here.

The split sleeve can be used for repairing broken or split pipe. There is a special kind of split sleeve made for repairing broken bells. This sleeve may also be used for joints that slip away from home. When repairing a section of pipe that needs several lengths, the pipe can be replaced and the last two pieces can be raised and "buckled in".

Worn out or broken steel pipe can be repaired with a flexible type coupling.

Broken transite pipe can be repaired with a special transite sleeve for transite pipe. Short machined lengths are manufactured whcich are inserted into the broken points of the line.

GATE VALVES

In a new system the maintenance of gate valves is limited most to the repair of stuffing boxes and valve boxes. There are also always cases where the valve is damaged but with careful installation this should be at a minimum. In such a case it is necessary to replace the broken part. Valve stems, gates, wedges or other parts can often be repaired with the body of the valve still in the main line.

In every system there is the need for annual valve inspection. This is done to find valves that are closed, or have some monir defect. Left hand valves should be clearly marked if not replaced.

When a valve is closed, and water still passes the gate, the valve should be opened just enough for water to pass under the gate. This usually washes out anything that is stopping the gate from closing properly. If the gate, is not effective after several repetitions of this the gate should be removed from the valve. Any obstruction below the gate can be removed and any worn parts replaced.

Some valves are hard to close and occasionally too much force is applied to them by say 4 or 5 men. When the gates are tightened down too much, they are sometimes warped and thus water can pass above the gates. The stem can also be twisted which will cause the gates to blind.

A record showing the accurate location of every main line valve should be kept. This should be detailes drawing showing measurements from various permanent marks or objects e.g. property lines, manhole covers, catch basins, fire hydrants, curbs, sidewalks, hydro or telephone poles.

Valve boxes should be kept up to a grade at all times. Some may have to be raised several times but in the event of an emergency it is important to be able to locate a valve quickly.

HYDRANTS

Of all the points of maintenance in a distribution system, hydrants could be one of the easiest of a little preventive maintenance is used when the hydrants are installed.

One of the major problems in larges cities and towns is the location of hydrants to be away from potential traffic damage. In cold climates with severe wintres it is very important that hydrants be pumped out immediately after use to prevent freezing and cracking.

A suggested procedure for hydrant inspection is as follows:-

1. Use a sonascope and listen for underground leaks.
2. Check gate valve and valve box.
3. With the caps on, open the foot valve and check the stuffing box and nozzle caulking.
4. Close the foot valve, remove the caps, and check the drain.
5. Flush the hydrant.
6. Check and grease the threads on the nozzles and caps.
7. Check obstructions to use.
8. Oil the operating nuts.

METERS

The most important and most obvious requirement of a meter is that it should register all flows accurately. Actual tests carried out on inaccurate meters would not register low flows. It was also shown that in most residential areas, about 27 to 54 per cent of the total consumption is at flows of less than 0.5 gall/min. Thus for an economic production and distribution of water, accurate figures of consumption to be applied to water bills must be maintained.

In some systems a time limit plan is used, such as five, seven or ten year plan. The seven year plan is about the average for most systems and they usually start off by pulling all meters out of service that have been in use for seven years or longer. The time limit plan is not always effective when for example the water being metered is non active and none corrosive so that a large percentage of meters become inoperative from broken registers. In such cases it is better to check the meter readings monthly from which it can usually be determined if inaccuracies are apparent.

TANKS

The life of a tank depends upon a thorough and regular inspection and prompt repair of it when repairs are necessary. Another item that determines the life of a tank and supporting tower is the type of water and weather conditions. The regularity of inspection depends on the type of systen used and its location.

Tank inspections should be made after every storm and flood. Regular inspections are usually made in the spring of that year. to allow plenty of time for repairs during the good weather.

The inspection is made to determine the extent of pitting or paint failure by blistering, peeling, rusting, or abrasion. It should also state whether or not the pitting is in spots and can be repaired by welding or whether the pitting is general and requires a new sheets or structural members. The inspection report should contain as must detail on the condition of the tank and any recommendations for repair.

During the inspection of the inside of the tank, some safety measures should be put into practice, because ladders and spider rods are usually the first to detoriorate.

CONCLUSIONS

We in the business of "manufacturing" potable water too often forget that the eventual target of our endeavours is the consumer, whether domestic or industrial. Bearing this in mind it must be obvious to us that our efforts in the pumping station or filtration, our calculations and measurements on chlorine feed rates and micro-strainer operation comprise the first step in reaching our target. The second step is the care and maintenance of the distribution system which is equally important for without due consideration to this our other activities can be almost meaningless.

Let us consider the factors involved in the distribution system which affect our final target. If leaks is the distribution system go undetected our consumers suffer through decrease in water pressure. We and the municipality suffer through loss of water and again the consumer suffers either through paying higher rates for water or higher taxes.

Where breaks occur in the system and proper cleaning and sterilizing is not carried out before and after repair then the consumer suffers with water which may be contaminated or have a taste, odour or colour. The bad publicity and possible health hazard from such occurences are certainly undesirable.

Neglect of the simple valve can cause extreme inconvenience to the consumer in the event of a line break, where it is necessary to close off much more of the line during repairs than is absolutely necessary.

Care and maintenance of meters should be rather obvious to ensure that no consumer is billed for a greater quantity of

water than was actually consumed and conversely no consumer is using more than he is paying for.

From this discussion it can be easily seen, that taking our starting point from the careful installation of an intelligently designed system, it is quite simple and relatively inexpensive to maintain the distribution system satisfactorily.

RECORDS AND REPORTS

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A record may be defined as a compilation or collection of figures, facts or data relating to an event or sequence of events. A report, on the other hand, is an explanation of the facts or figures that appear on a record.

The maintenance of records, or the collecting of figures to compile them is considered by many of us as a time-consuming task, a thing which someone thinks we should do, but for which many of us can see no important purpose.

Still, our very existence, professionally and otherwise, is one record after another and we maintain these records either mentally, to be forgotten as soon as the data is received, or kept in permanent form for future reference. Records are used, also for the regulation of daily affairs and future planning. We all keep them and use them constantly; e.g. a bank book which aids in guiding present and future expenditures. If we do not maintain a bank account we have no money, or we bury our wealth in a hole in the ground. Even in the latter instance we keep a record of where the burial spot is.

Again, we accumulate records of our car mileage and how much gas we use. As soon as we calculate the miles per gallon of gas used, for someone's information, we are making a report based on the data collected from our car mileage records.

Indeed, there is nothing peculiar about our maintaining records and preparing reports. Only the degree and the type of information desired differentiates between them.

We can apply the above to the operation of a water works or a water works system. The records we keep and the reports we make can be categoried as:

1. Operational records;
2. Maintenance records;
3. Statistical records;
4. Accounting records.

The information contained in each record may overlap depending upon how the record is composed. Data of an operating nature may also relate to maintenance and/or statistics. This information will vary with the type of plant, the size of the plant and the method of treatment, the source of raw water and the extent of the distribution system. Data recorded may be on an hourly basis, semi-hourly, once a shift, twice a shift, weekly or monthly basis. Your records may be volumnious or sketchy, but in each case relative to what you want or need in order to operate your plant efficiently. Regardless of the form in which you are required to accumulate data, you will probably record additional information for your own broader understanding.

Records relating to the operation of the treatment plant may include information incorporating filter runs, wash water used, pumps in operation, chemicals used, condition of the raw and treated water, flows, chemicals on hand and on order, chlorination rates, power consumption, power factors, periods of maximum electrical demands, weather observations, and results of laboratory control tests used by you to assure the adequate treatment of the water delivered by the plant. If your initial supply is from wells you will be interested in recording well drawdowns and rates of aquifer replenishment. If your supply is from streams or lakes you will, no doubt, desire to record stream levels or lake levels.

In order to set up a system of adequate records two essential elements must be remembered. Firstly, the form and extent of the records to be kept must be carefully planned. Secondly, a procedure must be established to insure the continuance of the records selected. This is most important because a given set of operating conditions, if not recorded immediately, can never be accurately reproduced.

In the case of distributing systems, the records relating to the operation and maintenance of the system are not static and definite procedure to insure that information will flow from the field to the control point are necessary. A record of primary significance to the operating and maintenance of a distribution system is a comprehensive map. This map should be on as large a scale as possible and should show all mains, main sizes, type of mains, valves, hydrants, streets, reservoirs, elevated tanks, wells, booster stations, and emergency interconnections with other systems. If possible, blow-offs, air release valves and normally closed gate valves should be indicated. The original map should be carefully stored and copies issued to operating personnel for their use. As the map must include the entire system, the scale may be too small to show the required detail. Therefore, to have an adequate record it will probably be necessary to divide the map into sections on separate sheets, using an adequate scale to show the requisite detail. Sectional maps must be accurately scaled so that adjoining sheets will co-incide. Information on sectional maps will show subdivions, lots, blocks, tracts, streets and easements, street names and widths, mains, size of mains, location, material, year installed, hydrants, type, class of hydrants, details relating to valves, service lines including size and location, and all other pertinent information relating to the system or section of the system under study. In other words, the section map is a magnified part of the major system map which enables you to read the fine print. In large distribution systems it has often been found advisable to enlarge or divide section maps for insurance to works foremen assigned to particularly congested areas. In preparing a section map it may not be possible to obtain all the desired information in an economically short time. This information may be omitted until it can be obtained without undue expense.

In any event, sectional maps are among the most important of all distribution system records. Supplementing these maps, and for use of the field crews, are valve records. Valve records are lists of all gate valves with their location, function and operation. Data is given as to valve number, size, make class, number of turns to open, direction of turns to open, street location, distance and direction from the principal street line or curb, and intersection or other information to help rapidly locate the correct valve.

Maintenance records on each section of main, each valve, hydrant, or blow-off on the system can be set up to show the

trouble experienced, remedy, time and material required to effect repairs, and the costs involved. By accumulating records of this nature, it is possible for supervisory personnel to evaluate types of material or equipment, forecast future trouble spots, set up preventative maintenance procedures and prepare maintenance budgets. Maintenance records can be most easily compiled and kept as a running record by employing card reference files.

The use of cards will:

(a) Simplify the procedure to be adopted for adequate maintenance and lubrication of all equipment.

(b) Establish correct time intervals between lubrication of equipment.

(c) Establish a policy of preventative maintenance for all equipment.

(d) Establish where possible, a standardization of maintenance practices and lubricants for more efficient and economical operation of plants.

(e) Remove from the operator the burden of remembering when maintenance and/or lubrication should be carried out.

(f) Provide an accurate lubrication record of each unit or piece of equipment.

Information on the card usually includes all pertinent information relative to the unit to which it refers. Each unit will have a card which will identify the equipment by a plant number and will list name plate data, serial number, manufacturer, supplier service representative, lubrication instructions by type and grade of lubricant and frequency of lubrication. A category on the card is for a brief description of repairs made, parts replaced, servicing and repair costs. Some operators color code the cards for lubrication inspection or overhaul periods. The use of colored cards will enable the operator to quickly identify equipment requiring various intervals of inspections, routine maintenance and lubrication. Periodic spot checks by the plant superintendant will give immediate indication of whether routine maintenance instructions are being carried out.

Much of the data accumulated on daily operating log sheets may be classed as statistical in nature. Such data deals with hourly flows, maximum and minimum flows, total flows, power consumption, quantities of chemicals used, water conditions, periods and times of maximum power demands, hours of pump operation, and many other factors that can be compared with past records and be used for forecasting future operating conditions. Close comparison of these figures show many interesting features. For instance, it has been possible by the collation of total flows to indicate to main crews that a leak has occurred in the distribution system. Cost of operation, total flows and plant capacity will provide data which may influence the provision of meters in the system or metered supplies to the users. Periods of maximum power demand will give you clues as to when to start auxiliary, mechanically driven pumping units thereby reducing monthly power bills and, in turn, plant operating costs. Total flows or maximum flows may indicate the necessity for increasing plant capacity or revising plant design.

All accounting records may not come under the jurisdiction of the plant operator, but information including inventory control, costs of maintenance, and time or payroll data do. From the point of view of the operator, the payroll records are highly important. If they are not accurate and if they are not submitted to the central accounting point on time, he necessarily, will receive complaints. With the development of machine accounting, many of the major accounting records are maintained in the form of punched cards. The advantage of punched cards is that much information can be included on them in a small space. Later, these cards can be used for billing procedures and collecting data.

Another useful record is the diary or daily log book. Many miscellaneoud incidents in plant operation do not fit into the regular records employed, however, they should be kept in some type of permanent form. Such information noted might include: occasional numerical data and measurements, maintenance items, replacements and repairs, start-ups, trouble and various methods tried for correction in start-ups or treatment, complaints from customers, visits by officials or authorities and their comments, reports from other agencies such as the Department of Health re inspections and tests,

and similar facts that an operator always appreciates having on hand. This data may be quickly referred to if the daily summary sheet of operation contains a cross reference. Instances arise where knowledge of the date of an occurrence, even without further detail, is helpful.

In this dissertion I have not attempted to relate what records should be kept, what data should be recorded, or how often data should be recorded. I have merely indicated a few suggestions as to what some operators may keep in the form of records. In the final analysis, the records you keep will depend on the type of plant you operate, the amount and category of information you require for answers to inquiries, and what information will enable you to operate the plant efficiently and economically. I have also tried to stress the great importance of accuracy and the need for continuity in your records. Also, attention has been directed to some of the ways in which this information is used. Finally, if records are carefully assembled and analysed, they can be of much assistance to you and to your supervisors.

SAFETY PRACTICES IN WATER WORKS

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Division of Plant Operations

INTRODUCTION

The theme which must be stressed in all safety work is that the greatest asset a water utility has is its personnel and good business dictates that this asset be protected as vigorously as possible. Thus, good utility management demands that a good well coordinated and vigorous safety program be instituted at all water utilities. The mere lack of safety program at a water utility would indicate that management is not alert to its duties.

A SAFETY PRACTICE PROGRAM

Before a safety program can be established, it must have the full co-operation and active support of management. It is imperative that one person in the utility organization be designated as responsible for the program. In a small water works system, that person may be the superintendant, while in larger organizations another person who can devote part or full time to the job may be so designated.

The next step in setting up the program is to provide for: (1) keeping injury records, (2) locating the hazards, (3) making equipment, plant arrangements and working methods safe, (4) getting employees interested in safety and (5) controlling work habits.

INJURY RECORDS

The keeping of injury records is basic to a safety program. With complete records, the program is given direction and is sure of success. The records should be short and contain space for all pertinent data. The forms should cover such items as: (1) accident report, (2) description of accident, (3) physician's statement, (4) corrective action taken and (5) accident analysis chart.

LOCATING THE HAZARDS

The person responsible for the safety program should constantly be on the alert for hazards which may cause an injury to an employee. One of the best methods of attacking this problem is to search the records for the conditions and situations that have produced injuries. Records such as this provide evidence of the need for a corrective program.

Many other sources of information on hazardous conditions are available. These include safety manuals, insurance company brochures, etc. These sources of information should be used freely and frequently.

EQUIPMENT, PLANT ARRANGEMENTS, WORKING METHODS

Nothing prevents accidents as effectively as the elimination of the causes. To preach safety while permitting unsafe conditions to prevail is bound to create an obstacle to the co-operation required from employees. Only when safety is integrated into the job are workers convinced that the man responsible for safety wants to prevent accidents.

EMPLOYEE INTEREST

To obtain maximum benefits from a safety program, it is essential that everyone in the organization become interested in and sympathetic to its objectives. The answer to full co-operation by the employees lies in a carefully thought out program, real knowledge of human beings and their actions, a knowledge of the work and of union organization and endless, painstaking thorough attention to the program by the people who administer it. A basic point is to get everyone in the safety picture at once, and keep them in it.

CONTROLLING WORK HABITS

There are always several ways to do a job, some of which are not safe. Work methods for all routine jobs should be analyzed and standardized on one safe way. These safe ways for doing a job should be impressed upon the workers until they not only accept the methods but the methods for doing the work become habitual. Thus, safety becomes a habit.

SAFE WORK PRACTICES

The accumulated records, statistics and information become of value when used for analysis because they permit closer concentration toward accident-prevention in the most hazardous areas. A study of the causes, the types and the sources of accidents may call for closer supervision, additional training and/or education in certain fields of operation. It is in this analysis that the safety program can make its best efforts and eliminate or minimize accidents and injury.

PHYSICAL EXAMINATIONS

An initial corrective measure in setting up safe work practices is the determination of the workman's physical ability to perform the duties at the time of his employment by requirement of a physical examination before employment. Many potential accidents can be eliminated at this point when physical defects can be found that may prove the workman's inability to perform a particular job. This examination may also reveal accident proneness or previous history of occupational accidents and injuries.

INDOCTRINATION

The indoctrination of new employees is very important. This should be done at the time of employment, again by his supervisor and then as on-the-job training by his immediate foreman. This is the point where the employee develops the safe work habit.

ON-THE-JOB TRAINING

Since safe work practices are the responsibility of the foreman as an essential part of his job, he must see that each workman fully develops the safe work habit. On-the-job training demands that safety be a part of job planning and job performance.

CORRECTIVE ENFORCEMENT

When the foreman-supervisor is assigned the responsibility for safety, he must also be given the authority to see that safe work practices and conditions are carried out. When an employee becomes an accident repeater or when he fails to maintain safe working practices or the proper personal safety attitude, efforts must be made to rehabilitate the employee through counselling, closer supervision or reassignment. Continued lack of co-operation or failure to comply with safety responsibilities should be the cause for corrective disciplinary action.

PLANT LABORATORY

Essential Items Required

Adequate lighting	Marked refuse containers
Adequate ventilation	First Aid Kits
Draft hoods	Deluge showers
Appropriate signs & notices	Protective clothing

OPERATING SAFETY INSTRUCTIONS

1. Laboratory glassware must not be used for food or any other use than what was intended.
2. All bottles and containers must be clearly marked that the materials they contain can be clearly identified.
3. Suction bulbs will be used on all pipettes.
4. Access areas around shut-off valves and top areas of the sink and counter must be kept clear of unused equipment at all times.
5. Oil or greases must not be used as lubricants when making glass to hose connections on any laboratory equipment. Use only water or water soluble lubricant jellies.
6. Gloves should be worn when making glass to hose connections.
7. All glassware must be kept clean by using detergent solutions for general cleaning or by soaking the glassware when necessary in a cleaning solution of sodium diochromate and concentrated sulphuric acid.

8. Chemicals that cannot be identified must be disposed of. Suggested methods of disposal-dilution, incineration, dumping, etc. This is to be done only by someone who understands the risks involved.

9. A thorough knowledge of first aid for dealing with accidents involving chemicals, gasses, glass cuts, infections and burns of all types.

10. Bottles containing hazardous liquids must not be stored in high places where it is necessary to climb up to or reach above the head to get them. Store them in lower shelves by themselves.

VENTILATION

Meter shop, acid room or other areas where solvents or other compounds are used and stored must be well ventilated. The working area should be designed and constructed for the safety and convenience of the worker and for his efficient production. The ventilation should be by mechanical means with the air intake drawing air from the outside and in rooms where lime and other dry types of chemicals are used, dust accumulators should be installed in the air discharge pipe.

ALUM

Protective dustproof equipment and proper clothing should be worn by personnel handling and storing. Skin and nose irritations may be avoided by the use of plenty of water in washing and bathing.

AMONIA

Cylinders should be stores in a cool, dry, ventilated place and handled with care. Protective equipment should be available while handling and in case of leaks, only trained personnel should make repairs. First aid practices should be known to persons handling and using this material.

ACTIVATED CARBON

Storage should be in a dry fireproof space. Activated carbon should be handled with protective dustproof equipment. Smoking must not be permitted while working with or near stored material. Plenty of water should be used in washing and bathing.

CARBON MONOXIDE

Work on engines using gas, gasoline or diesel fuel should be carried out in well ventilated areas. Improperly vented gas heaters should be corrected.

FLUORIDES

In addition to the precautions given for liquid fluorides, all personnel should be given detailed instructions in the hazards involved in handling the dry material. Important points are: avoid breathing fluoride dust, wash thoroughly after handling and clean up spillage. In addition to good dust respirators, chemical goggles and dust-resistant clothing, persons handling fluorides should wear rubber or neoprene covered canvas gloves and rubbers or robber boots on the feet. Handling points and dry feed equipment should be equipped to keep the dust hazard at a minimum and such areas should be well ventilated.

Great care must be taken to prevent fluoride dusts from entering open cuts, sores or lesions on the skin. It has been found that sodium fluoride absorbed through cuts in the skin acts upon the central nervous system and repeated exposures of this type can cause paralysis of the brain. Animals dusted with 1/2 ounce of sodium fluoride in five pounds of fine silica have suffered loss of weight, stiffness of the back and finally prarlysis of the spine. The need for a thorough washing after handling fluorides is obvious.

Containers that have held fluoride compounds should be disposed of at once by persons who understand the hazards involved.

HYDROFLUORIC ACID

Tha standard label for these material read:"Corrosive Liquid" - "Poisonous". These labels really mean what they say. The vapor or liquid material is very dangerous when it comes in contact with the eyes, skin or any part of the body, or if taken internally. When in contact with the skin, it can cause painful and slow healing burns. Burns by solutions weaker than 20% may not become noticeable for some hours, so the importance of an immediate change of clothing and a good shower should be obvious and these should be standard procedures. More than 50 ppm of the fumes in air is known to be fatal in an exposure of 30 to 60 minutes.

From the foregoing information we can understand the nature of the severe chemical hazards involved in handling and storage of this material. Any tendency to minimize the seriousness of these hazards should be discouraged. The hydrofluoric acids should be stored in lead carboys or in neoprene or rubber lines steel containers. Both acids are very corrisive to most metals and even the fluosilicic acid will eat its way through a 1/4 inch steel plate in a few minutes. Several materials for tank linings have been tested, of which neoprene, soft rubber, hard rubber and certain plastics have proven successful. We are using the soft vulcanized rubber lining for our hydrofluosilicic acid tanks. All storage containers should be equipped with an auxiliary tray or confining walls to catch the contents of the container or tank in case of a leak. Remember that if this acid comes in contact with metals, hydrogen gas is given off which might be an explosion hazard. This information points out the need for storing the acids in an isolated place, well ventilated and equipped with explosion-proof lighting. Storage containers or rubber lined pipe extending to the outside of the building at a point where there is no danger to equipment or personnel from any flourine fumes. Feed pumps should be of the diaphragm type, with a totally enclosed system of plastic or rubber lined pipe, from the storage tank to the point of application. The pipe for conveying the material should be located so that there will be no danger to personnel or equipment from accidental leaks or sprays. Wrapping the pipe joints and fittings with self-sticking plastic tape will offer considerable aid in protection from sprays from overhead lines. Finally, post the acid storage and equipment areas with proper warning and danger signs to keep away unauthorized persons. Containers that have held fluorine acids should be disposed of by personnel who will take the necessary precautions to do it safely.

Protective clothing and equipment of the best quality should be on hand for all personnel who must handle and maintain hydrofluoric and hydrofluorsilicic acid equipment. Such equipment should include long gauntlet type rubber gloves, high rubber boots or waders, short type rubber raincoat and chemical safety goggles with a plastic face shield. If there is danger from strong vapours (maximum allowable concentration in air, 3 ppm) or spashes, an air-supplied plastic hood or an air-supplied respirator should be used. Under any circumstances, make sure the eyes are protected as a tiny drop of the acid in the eye can quickly cause ulceration of the eyeballs. Bubbler

fountains equipped with warm water for the eyes and safety showers for washing protective clothing, even before it is removed, should be standard equipment. All protective equipment should be thoroughly washed before and after using. If the material comes in contact with the skin, the use of a drenching shower immediately is important. Temporary relief can be obtained by treating the acid burn with apiece of ice, alcohol or magnesium sulphate while waiting for medical help. Hands or feet can be dipped into a five percent solution of magnesium sulphate for 30 minutes. As with most chemical handling, a good scrub-down in a warm shower at the end of the day should be mandatory.

Any splashes or spills should be cleaned up immediately. Don't leave a dangerous trap for a fellow worker. Flushing and scrubbing with soap and water will usually clean up small spills. Lime water left on the spill area for half an hour will usually neutralize any acid that may have soaked in. Clean this up also as it will still contain some fluoride compounds. Dispose of clean-ups and waste material in a safe place where there will be no danger to others.

LIME

Protective dustproof equipment should be used while handling and a dust collecting system used, if possible. Storage should be in a ventilated, dry area. Plenty of water should be used in bathing and washing to prevent irritations and physicians should be consulted if irritation becomes severe.

SODA ASH

Soda ash should be handled in the same manner as described previously for lime.

SOLVENTS

Care should be taken when solvents are used in confined areas. The area should be well ventilated. Solvents should be cleaned from skin to prevent irritations.

AIR HAMMERS - TAMPERS - PAVEMENT BREAKERS

Each operator should be thoroughly instructed in the use of this equipment. Foot guards and eye protection should be worn. No horseplay should be tolerated. Routine checks should be made of the equipment and it should be maintained in good condition.

AUTOMOTIVE EQUIPMENT

Drivers must be licensed operators and know and observe all traffic regulations. Drivers should be instructed as to responsibilities for company equipment: to see that equipment is always in safe driving condition, to report the need for necessary repairs, to know procedures for reporting accidents and injuries and to attend periodic safety meetings of equipment operators.

BARRICADES AND TRAFFIC CONTROL

An adequate and safe work area must be protected. Sufficient traffic cones and barricades should always be carried by crews assigned to construction or maintenance work in streets. Barricades should be painted bright, visible colours and maintained in good condition. Warning signs, flags, flares should always be adequate and in positions where they can be observed easily.

BUILDING MAINTENANCE

Periodic inspections are necessary to eliminate hazards (fire, safeguards, etc.). Suggested repairs for safety should receive immediate attention. Floors, hallways and stairways should always be well lighted, clean, orderly and free from oil, dirt and debris. Immediate repairs of hazardous electrical outlets and fixtures should be routine. Adequate sanitary facilities for employees must be provided. Hand rails on steps and stairways should be provided and used. Good housekeeping should be provided and used. Good housekeeping must be maintained.

CALKING AND USING LEAD

Proper eye protection must be used. Proper tools in good working condition should be employed. Lead melting should be done out of work traffic, by workmen using the protection and gloves and having thorough knowledge of handling lead.

CHLORINE HANDLING AND TRANSPORTATION

Chlorine is one of the work horse chemicals of industry and in any discussion of the subject it is well perhaps to consider first some of the properties of the chemical.

Despite the fact that chlorine handling equipment is well designed, a fact well proven by the number of people who have been handling chlorine for many years without an accident, it must be recognized that chlorine is a potential killer if equipment becomes defective or people become careless.

There is no such thing as a fool proof method of handling chlorine. Therefore, we will deal with the potential hazards which can be avoided or eliminated if the lethal properties of chlorine are recognized.

By itself, chlorine is not explosive nor is it flammable, but it will support combustion.

For example, steel at a temperature of 483°F will ignite in the presence of chlorine and burn quite readily. Other metals will act similarly at slightly higher temperatures.

The least detectable amount of chlorine in the atmosphere is about 3 1/2 ppm, but the maximum amount that can be inhaled for one hour without serious effects is about (4) four ppm. At (15) fifteen ppm, chlorine will cause irritation of the throat; at (30) thirty ppm, it will cause serious spells and at (40) forty to (60) sixty ppm, it is extremely dangeous for one half hour exposure. A few breaths of air containing 1,000 ppm would be lethal.

The following first aid steps should be taken in case of chlorine accidents:-

(a) Remove injured to open air.
(b) Call physician.
(c) Lay injured person on back, keep warm and quiet and start artificial respiration if unconscious.

(d) Administer hot black coffee.
(e) Apply burn lotion or oil for relief of skin irritation.
(f) Relieve throat irritation and coughing.

OPERATING SAFETY INSTRUCTIONS

1. A canister type respirator must be work when it is necessary to locate and stop small leaks in the piping or when making any repairs or adjustments to leaking equipment.

2. Wear plastic coated gloves when changing cylinders.

3. When connecting the piping from the cylinder to the chlorine machine or whenever it is necessary to break a connection and recouple it, a new lead or fibre washer must be used each time.

4. Do not lift a cylinder (150 lbs) up unto the scales, use a ramp.

5. Whenever possible, two men should be present when changing chlorine cylinders (150 lbs.) (1 ton).

6. If there is any taste or smell of chlorine while wearing a canister type mask, the canister must be replaced with a new one immediately.

7. A canister type mask is recommended for a concentration of 1% or less of chlorine. If the concentration is 2%, then the maximum time an operator can stay in the area is about 10 minutes.

8. The industrial type chlorine gas mask does not offer any protection against oxygen deficiency or gases other than chlorine.

9. In cases where the chlorine concentration is high or the oxygen content is less than 16%, supplied air types or selfcontained breathing respiratory equipment must be used.

10. A self-contained air breathing unit must not be used unless the air cylinder is fully charged. Cylinders should be completely recharged after each use.

11. When a leak occurs in a chlorinator room, do not open or leave open any doors leading into any other part of the building. Only doors to the outside should be opened.

12. Water should never be applied to a chlorine leak because of the added corrosive action created by the water and chlorine mixture.

13. The chlorine exhaust fan must be turned on at all times when entering the chlorine room, whether for a routine check or for servicing or repairing leaking equipment while wearing a mask.

14. In all cases where the concentration of the chlorine gas in the air is unknown, it should be assumed that the concentration is greates than 1% and a self-contained respirator worn.

15. Do not start up or operate a chlorinator or turn on a chlorine cylinder unless adequate protective equipment (canister type or air pack respirator) is on hand at the chlorine room area.

16. All persons using the gas protective equipment must be trained in its use and maintenance.

17. Canister type masks shall be kept in a dust proof container located in a conspicuous location outside the area of possible contamination.

18. All removable parts of the chlorinator such as cylinder clamps, metal hose connections, couplings, headers, valves etc. should be removed at the end of the chlorinating season, cleaned and inspected; worn and damaged pieces replaced.

19. When using chlorinated powder or chloride of lime for dusting, etc. a proper type of eye shield and gloves should be worn.

The piping from the cylinders to the header located on the wall and from this header to the chlorine machine must have an inverted loop in its length to prevent water from the chlorinator backing up into the cylinder in the event of a plugged overflow pipe in the chlorinator.

AIR COMPRESSORS

Air compressors should be inspected periodically. Necessary repairs should be reported and repairs made immediately. Trailer hitch connections should be made and secured safely. Equipment should never be refueled while in operation. Hose connections should be maintained securely.

HOISTING CRANES

Only trained and authorized personnel should operate hoisting equipment. Hoisting gear should be adequate and proper for the load. The operator should stop equipment immediately when hazardous condition develops.

DOG BITES

Dog bites are a definite hazard to meter readers and outside workmen and should receive prompt medical attention.

ELECTRICAL CONSTRUCTION AND MAINTENANCE

Only authorized and fully competent personnel should be assigned to work with electrical equipment and maintenance.

Switchboards and equipment should be designed and located in clear, well lighted, accessible, insulated areas. Personnel should wear insulated safety hats when working in hazardous areas. Safety equipment should always be available.

An electric shock victim must be given prompt and correct attention immediately. However, the rescue and resuscitation of a shock victim requires considerable skill and should be attempted only by those trained in this type of rescue work.

FIELD ELECTRICAL HAZARDS

Checks should be made for electrical hazards on construction or maintenance jobs when work is planned.

ELEVATORS

Only authorized personnel should operate elevators; controls should be tested daily before operations begin. Proper warnings and signs should be posted and area kept clear when elevators are being repaired or out of service. Periodic inspections should be made.

EXPLOSIVES

Explosives must not be used by any other than authorized, experienced and certified personnel. Extra precautions should be taken by the foreman-supervisor in regard to the safety of the operator, the area, the job and the equipment.

FALLS

Since many serious accidents and injuries occur because of falls, employees must frequently be cautioned of this hazard.

Good housekeeping prevents many accidents from falls - objects falling and the person himself falling. Work area should

be clear and orderly. Stairways and floors should be clear, clean and orderly. Safety belts should be used when workmen are in akward positions or in high places.

FIRE PROTECTION

Good housekeeping is the basis for fire prevention. Inspections should be made periodically and correction of fire hazards should be made as soon as practicable. Local fire departments should be consulted for recommendations.

HAND TOOLS

Hand tools, improperly used and in unsafe condition, are the cause of many accidents and injuries. Therefore, the right tool should be used for the right job in the right way. Protective safety equipment should be used where there is a job hazard. The work area should be in a safe condition, clear of hazards, with an adequate working space allowing a solid footing. Tools should be in good condition and used for the purpose for which they were intended.

HORSEPLAY

No horseplay should be permitted on jobs. Many serious accidents and injuries are caused by horseplay and immediate corrective action should be taken if it is repeated.

INSPECTIONS OF TOOLS AND EQUIPMENT

Periodic inspections should be made of tools and equipment so that those that are broken or worn out may be replaced. Worn or broken equipment should be reported and replaced or repaired as soon as practicable.

LADDERS

Ladders should be inspected periodically and maintained in good order. Safety belts should be used when akward positions are necessary for the work. Metal ladders should not be used for electrical work.

LANDSCAPING

Personnel should be properly trained in the use of power equipment, especially power lawnmowers. Equipment should be

completely disconnected and care should be taken while repairing or cleaning equipment. Safety belts should be used if workers are required in high or hazardous places.

LIFTING

Lifting should always be done with the leg muscles instead of the back and footing should always be secure. Knees should be bent and back kept straight and body must not be turned or twisted when lifting. Assistance should be secured if load is too heavy or awkward to handle. Use mechanical device for lifting wherever possible.

OFFICE SAFETY

Working areas should be adequate, well ventilated, properly lighted and arranged so that desks, chairs and equipment will not be hazards to passage to work. Good housekeeping is important. Electrical equipment should be repaired by qualified personnel only. Horseplay must not be permitted.

PAINTING

Inside painting should be carried out in a well ventilated area. Proper protective masks should be used when spray painting. Good housekeeping is essential in order to prevent fire hazards. Care should be taken as to the proper use of ladders, scaffolds, etc. and safety belts should be used when working in high or hazardous positions.

PORTABLE AND POWER TOOLS

All equipment should be safeguarded by grounding. Wiring and equipment should be checked periodically for defects. Extreme care should be taken when equipment is used in wet areas.

Protective safety equipment should be used when using grinders, buffers, or other tools if there is a danger of flying material.

PROTECTIVE SAFETY EQUIPMENT

The need for protective safety equipment in an accident prevention program has proven its valu many times and the program cannot be successful is any phase of accident prevention is overlooked.

Safety equipment should be used as designated and its use should be compulsory by workmen performing hazardous work. Eye

and face protection should be used in jobs where there is any possibility of injuries, that is, from hand tools, power tools, welding equipment, etc. Foot protection should be used to safeguard against injuries while breaking pavements, tamping trenches, handling materials, etc. Head protection (safety hats) prevent many serious injuries in construction, excavation or electrical work. Hand protection (gloves) should be used to prevent injuries occuring when handling materials, sharp objects, chemicals or electrical equipment. Masks and respirators should be used when such hazards exist such as chlorine, painting or dusty areas. Prevention of accidents due to falls can be minimized by the use of safety belts, scaffold, etc.

SANITATION

Washrooms, toilets, locker rooms, drinking fountains and showers that are clean, ventilated and adequately built keep good employee morale. Adequate, clean drinking water and paper cups should be available to workmen in the field. Sufficient showers should be available at each plant, especially if the employees are exposed to skin irritant materials.

STAIRWAYS

Stairways should be well lighted, clear and orderly and have hand rails. Caution signs should be posted to draw attention to the safe use of stairways and hallways. Steps should be always clean and skidproof material properly installed, if necessary, to prevent slips and falls.

STORAGE AND HANDLING MATERIALS

Mechanical hoisting equipment should be used on heavy or bulky materials when lifting or handling hazards are present. Personnel handling material should be instructed in the proper method of lifting.

Proper protective equipment should be used when material being handled requires its use. Material should never be suspended over workmen, Storage space in material yards and storage rooms should be adequate, clean and orderly. Pipe storage should be in an accessible area, properly and securely stacked and well braced.

STORE ROOMS

Good housekeeping must be maintained at all times. Space should be well arranged to permit proper storage, handling and

movement of materials. Inspections should be made periodically for fire hazards. Fire extinguishers should be in good order and easily accessible location.

ELEVATED TANKS AND RESERVOIRS

The ground area surrounding elevated tanks and reservoirs should always be neat, clean and landscaped, if possible. Tanks and reservoirs should be kept in good condition. Protective fencing should be provided to keep out unauthorized persons. Ladders should be securely fixed. Safety belts should be used when working in high or hazardous positions. More than one workman should be present for work or inspections. Care should be taken when power equipment is operated to eliminate electrical hazards.

TOOLS AND MACHINES

Protective equipment should always be used when operating power equipment where there is any chance of flying objects or other injuries. Inspections should be made of all tools and equipment for safe operations and necessary repairs or replacements should be made immediately. Repair of power tools and machinery should only be made when the equipment has stopped.

TRENCHING (EXCAVATION - SHORING)

Safe and adequate work area should be well protected with barricades and traffic safety cones for the protection of the worker and the public. Proper and adequate tools and equipment should be available for the job to be done.

Workmen should use proper protective safety equipment, that is, safety hats, goggles, foot guards, shields, etc. Inspections of the trench should be made for possible hazards - checking for possible cave-ins, projections inside trench, housekeeping, etc. Equipment should be operated by authorized and qualified workmen only.

Since most serious injuries occur in the field, extra precautions should be taken of work safety and conditions of men in the trench. Never take chances while workmen are in the trench. Proper shoring and bracing always pays.

TRUCKS AND EQUIPMENT

Trucks and equipment should have routine inspections made. Need of repairs should be reported and made as soon as practicable.

Only qualified and licenced operators should be permitted to use and operate vehicles and equipment. Operators and drivers should not permit riders on equipment or permit passengers on trucks or equivalent equipment when it becomes hazardous. Electrical or other hazards should be checked constantly when moving heavy equipment.

WELDING

Proper protective equipment should be used at all times. Checks should be made for possible fire hazards, cutting or welding in areas of inflammable or explosive mixtures. Only authorized or capable personnel should operate welding equipment.

WORKING AREA

A safe working area must be provided for efficient work to be done. In the field, traffic should be controlled by the use of traffic cones, barricades, flags, etc. to give protection to the workmen as well as to the public. In the material yard and store rooms, good housekeeping and properly planned storage and work areas must be provided to permit safe working practices. In the shops, plants and offices, planned arrangements must be made to provide safe working areas to enable the most efficient production.

CONCLUSION

Through continuous research and accident experience, standard safety rules and safety devices have been worked out for most of the operations which are common activities in water utilities. We, as supervisors, are expected to know about these rules and devices, and we also are expected to use them. We must broaden our horizons in safety, by learning what others are doing, so that we may have a wider understanding to help us work out protective devices and safe practices of our own to fit our own operations. No matter how perfect the mechanical device or how thorough the research and development have been, the degree of hazard for safety of the operation rests in your hands.

ALGAE AND MICROSTRAINING

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INTRODUCTION

This lecture on Algae and Microstraining has been prepared to furnish the plant operator with a basic understanding of what algae are, the problems they create, and some discussion on the means available for their control. It is obvious that a life time could be spent on the study of any one of these topics without exhausting the problems for research so that in the hour available we will only touch on some of the principles and items of particular importance to the operator. In the demonstration period there will be an opportunity to observe some of these organisms. It is intended that later sections of this course will include more advanced information and some practice in identification and counting.

WHAT ARE ALGAE

Algae are plants just as trees and grass are plants. They are green, they manufacture their food in the form of starches or oils by using the energy of sunlight and the nutrients they extract from the water. In the classification of plants they are considered to be the most primitive group and some of the algae forms commonly found in water supplies are thought to be similar to the first life on earth. They are considered primitive because each cell

is capable of carrying out the complete life history as no specialization has been developed into various tissues such as are found in the higher plants i.e. stems, roots, leaves or seeds.

VALUE OF ALGAE

The Water Works operator often looks upon algae as purely a nuisance as it clog filters, creates nuisances and imparts tastes and odours in the water supply. Algae are, however, the basis of all life in water. On land, grass feeds the rabbit which in turn is eaten by the fox and while the fox does not eat grass, there would be no foxes if there were no grass. This is called a food chain and tha basis of the food chain in water, is algae. These plants feed minute animals that are in turn eaten by minnows which in turn provide the food for pickerel. Thus, if there were no algae there would be no pickerel. It can be demonstrated that fish production in a lake varies directly with the amount of algae that it produces and thus while it may be a disadvantage in a water supply, it is not unnatural and is a necessity for other uses we make of water. When the first men start making long distance trips into space, the food they will consume will be algae grown in the space capsule.

SIZE AND DISTRIBUTION

There are several thousand different species of algae that live in the waters of Ontario. These range in sizes from a plant as much as four feet tall down to cells which are so small that they can barely be seen when magnified a thousand times in a microscope. Algae live in almost any place where there is moisture and sunlight. In addition to living in the oceans, lakes and rivers down to the depth where the light can penetrate, they also live on the damp soil on the face of glaciers, and in combination with fungi to produce the lichens we are all familiar with.

GROWTH REQUIREMENTS

Algae are very specific in their needs. The types that are characteristic of lakes are seldom found in streams and those which populate a lake in summer give way to other forms in winter. Some species can only live in very pure water and others are obligated to polluted situations and even sometimes to particular types of pollution. Factors governing the type and number of algae are enviromental such as temperature,

available light, nutrient concentration, and so on. No two species have exactly the same requirements.

ALGAE PROBLEMS IN THE OPERATION OF WATER SUPPLIES

The operator can be faced with problems created by algae of several kinds. In all cases, they result from an over-abundance but the numbers required to create this difficulty will vary.

FILTER CLOGGING

The reduction of filter runs, caused by the coating of the surface of the filters with large numbers of these minute plants, is probably the most common and serious problem that algae create for the Water Works operator. Certain waters at certain times of the year produce a great abundance of the filter clogging species and under the worst conditions may reduce the production of water through a filter to a point where there is hardly sufficient to back wash it. The lake diatoms are the most common trouble maker in this regard, but certain of the summer blue-green algae will also develop in sufficient numbers to reduce filter runs.

The obvious way to solve the problem of short filter runs is to remove the algae before they get to the filter. The common method of removing algae from raw water is the use of settling basins which may follow flocculation and pre-chlorination. Microstrainers are also being used to remove the algae before the water is filtered. A third method is to apply algicides to the raw water and thus remove them before the water enters the plant.

The principle of removing algae by flocculation and sedimentation involves trapping the algal cell in the alum floc and carrying it to the bottom with other unwanted solids from the water. When algae populations are very high they often hold the floc in suspension long enough for it to pass through the settling basins and onto the filters. This floc and the algae can be settled if weight can be added to the floc. A slurry of ordinary clay mixed and fed during the periods of difficult times will do much to get the operator over a short term period of difficulty. Increased dosages of alum and heavier pre-chlorination will also assist in alleviating short filter runs.

Where short filter runs create a chronic problem or where the capacity of a plant is limited by high algae populations at certain times of the year, microstraining can be used to remove most of the algae before the water reaches the filter. This and chemical treatment will be discussed more fully later in this talk.

ALGAE AND TASTES AND ODOURS

Algae are capable of producing tastes and odours that will persist through treatment and cause consumer complaints. The whole subject of tastes and odours is the subject of the next paper but perhaps a little repetition will be of value.

There is much published information on taste and odour problems caused by algae. Different algae have been shown to cause different flavours and odours that have been variously described as pigpen, grassy, musty, cucumber, etc. While there is no doubt that these problems do occur it has been observed that in this province most of the difficulty does not come from algae but is the result of the decomposition products of the rooted aquatic weeds. Raw water supplies that come from shallow weedy lakes almost invariably have a continuous or intermittent problem with tastes and odours. This problem is usually most acute late in the fall when the ice cover is first formed and again in the spring at the time of the break-up of ice cover.

Two methods are commonly used in controlling tastes and odours; one, the feeding of activated carbon and two, variations in the method of chlorination. Activated carbon is the only sure method of taste removal, but this on a continuous basis is somewhat expensive. The use of chlorine dioxide or chloramine at various points of application in the plant may assist in controlling tastes and odours but this is an individual problem with each Water Works and can only be determined through experimentation.

One of the common sources of tastes and odours to a water treatment plant is the decomposition of accumulations in the settling basin. A number of instances have been observed where water leaving the treatment plant was in poorer condition than the raw water coming in. A short term routine in cleaning settling basins should be practiced by all Water Works in order that the decomposition products from the accumulated solids do not impair the quality of the water.

GROWTHS IN RESERVOIRS

A third common problem that algae create in Water Works operation is the growths in reservoirs. Here the algae may grow attached to the walls where they form a heavy mass of material alive with crustaceans and insect larvae. Or it may be the free floating type similar to that removed at the filtration plant. Either one may impart tastes to the water and the odd little animal that comes through the taps may shake the confidence of the consumer in the purity of the supply. Probably the most common algae causing difficulty in reservoirs is one of the large species called Chara. This algae grows to a height of two or three feet in a soft mud bottom and is typical of the cold hard water commonly found in spring water sources. Where such water is collected and stored in an open reservoir this algae invariably grows and is difficult to control.

CONTROL OF ALGAE

There are two basic means of controlling algae and solving the problems that they create; one, by controlling the environment in such a way as to make it an unsuitable place for them to live, and two, by killing them with chemicals. The latter method is less satisfactory in the long run as it necessitates adding chemicals that are costly on either a continuous or intermittent basis. Controlling the environment is a more satisfactory means, though this is not always possible.

ENVIRONMENTAL CONTROL

The exclusion of light is probably the most common environmental control. The easiest method is simply to cover the reservoir, although this is often not done and algae problems continue year after year. A second method of reducing light is to use activated carbon to induce an artificial turbidity. While this is only a temporary measure and must be repeated every few days, it has the added advantage of absorbing taste and odours from water while in suspension and keeping the bottom accumulations sweet. Carbon can only be used in the raw water where the treatment following includes good sand filtration. Another method of excluding the light would be covering the reservoir with black plastic. While this has not been used it would be effective in excluding light and be relatively inexpensive and easy to apply.

The regulation of algae growth by controlling the nutrients is not always possible though effective where it can be applied.

In choosing a new supply care should be taken to utilize water of low fertility as judged by chemical analysis and the algae population that it maintains. In this case a limnologist should make several inspections at various times of the year to determine the numbers and kinds of algae present and to assess the suitability of the water. Where the municipality controls the land adjacent to the supply, care should be taken to keep out surface drainage and other possible nutrient sources. Run-off from farm buildings, domestic sewage and certain industrial waters are rich in plant nutrients and should be avoided as only small amounts of these fertilizing substances can induce the development of high algae populations.

CHEMICAL CONTROL

While there are many algicides sold today, only two are suitable for use in a domestic water supply, namely copper sulphate and chlorine. The cheapness and availability of copper sulphate and its safety from a public health standpoint make it the most satisfactory chemical to use. The effectiveness of copper sulphate varies somewhat with the chemical composition of the water. In hard water the copper precipitates rapidly and thus more is required than in soft water. As a rule a thumb, 0.15 ppm will kill most organisms in surface waters. Copper sulphate is very toxic to fish and 0.5 ppm. is about all they will stand. Chlorine is sometimes used as an algicide especially where water is taken into a holding basin. A residual of 1.ppm. will kill most algae forms. While chlorine is more expensive than copper its use is understood by operators and equipment is usually available for feeding it.

In applying chlorine, a rough calculation must be made of the volume of water being treated and the pounds of chlorine required to satisfy the demand and still provide a residual of 1. ppm. The calculation is used as an initial guide, then followed by chlorine tests to provide the final adjustment. A similar calculation must be made for determining the amount of copper sulphate but more care must be exercised as no simple test can be used as a guide. To do this, the surface area of the water to be treated must be obtained together with the average depth of the water. When multiplied these two figures give the volume of water in cubic feet. The total number of pounds of water may then be calculated by multiplying the volume by 62.3. As one part per million (ppm) equals 1 pound per million gallons, the treatment of a reservoir with 0.5 ppm. would require one half a pound for each million pounds of water.

Area x Average depth x 62.3 - lbs.of water in reservoir
1 ppm. - lb. per million lbs of water

Copper sulphate is sold in a variety of crystal sizes. The method of application varies with the grade of crystal used. In general, the finest crystals may be distributed on the surface of the water as they will immediately dissolve. Larger sized crystals may be dissolved in water and pumped as a spray or they may be put in a burlap bag and towed through the water in such a way as to provide an even distribution of the calculated amount of chemical over the entire surface of the reservoir. The operator must know the depth of water as he applies the chemical and see that the deeper water proportionally more chemical than the shallow areas.

The ideal time to apply chemicals is when the algae population is rising but before the condition becomes acute. If treatment is postponed until a very dense growth of algae occurs the sudden killing of this material and the subsequent decomposition may remove all the oxygen from the water causing it to go septic, kill the fish, and become foul tasting. If the condition gets out of hand before treatment can be applied half the reservoir should be treated first to reduce the population, and after a week or so has been allowed for this material to decompose the total reservoir area can then be treated.

MICROSTRAINING

Microstraining as a method of water treatment has been introduced into Ontario within recent years, and there are now five installations operating on municipal water supplies. The development of this means of filtration was made possible by the invention of an extremely fine wire mesh capable of removing such small particles as algae from the water and yet capable of passing high volumes of water. The principle of the microstrainer is simply a rotary screen where the raw water is fed to the inside and flows out through the screen material. The drum is about three quarters immersed and as it turns around, a jet of water played on the surface of the screen knocks down the accumulated solids into a hopper and from there are carried to waste.

In water treatment the microstrainer has two uses: (1) as pretreatment for algae removal ahead of conventional sand filers, and (2) as sole treatment for waters for the removal of algae and other extrandeous material where turbidity is not a problem. It has been our experience that they have proven very effective in extending the operating time of conventional sand filters during times of heavy algae blooms.

In one instance, runs of not less than 20 hours have been obtained where previously 6-hour runs in summer were not uncommon and as little as two hours were experienced. Where this equipment is used as a sole means of water treatment it should never be installed with the thought of reducing turbidity. Where it has been used solely for the removal of algae and the protection against the variety of water fleas, insect larvae, leeches and aquatic worms, that commonly pass through unprotected water supplies, it has been found to be very satisfactory.

OPERATION

Some of the microstrainers installed in the province have been set up on an automatic control system and some are operated manually. The system used will depend on the individual plant. In general, they are easy to operate and require the normal lubrication and an occasional wash down. Over a period of time some permanent plugging of the screens will take place that is not backwashed by the water jet. When this occurs, the strainer must be drawn down and a 12% sodium hypochlorite solution applied directly to the fabric while the screen turns over slowly. It should be emphasized that concentrated chlorine solutions from a chlorinator or from chlorine powders are not effective in rehabilitating the screen capacity.

The reason for the sliming of the fabric is not well understood. The time between washing has varied anywhere between one day and six months and in one or two instances difficulties due to lessening of filter capacity over a period of one or two days have occurred. In all cases, the screens have been quickly rehabilitated with the hypochlorite wash and an investigation is now underway to obtain a continuous method of protection against this short term loss of capacity.

WATER MAIN INFESTATIONS

While water main infestations do not necessarily come under the title of this paper, there has been considerable interest in this matter in the past year, and so perhaps a little of the fact and fiction should be separated.

It is probable that most if not all water distribution systems contain living organisms of some kind. A brief survey of the literature indicates the wide variety of animals that have caused difficulty from time to time. These have included nematodes, aquatic earth worms, snails, clams, a variety of aquatic insect larvae, leeches, Gordian or horse hair worms,

Daphnia or water fleas, etc. Many of these have occurred in municipal supplies having complete treatment of flocculation and sand filtration. The method of entering the distribution system often remains a mystery though in many cases it is thought that the minute egg passes through the sand bed and develops subsequently in the distribution system. This problem is not more widespread because the inside of a water main is relatively clean so that food is available only in very limited quantities. In some cases the life cycle cannot be completed entirely under water so that insects such as blood worms cannot reproduce in the water main.

NEMATODES

Earlier this year an article on worms in the drinking water in a leading U.S. magazine aroused the public and many inquiries were directed towards this organization and undoubtedly the municipalities.

The worms referred to were round worms or Nematodes. These are very small animals barely visible to the human eye. Some authorities consider them to be the most numerous animals on earth as they are found in the soil on lake bottoms, along the shores, in sewage sludge and in fact in almost any sample of earth. In view of their great numbers, it is not surprising that a few of them find their way into water distribution systems. Here they are able to subsist on the thin coating of slimes lining the water main and in organic depositions in low flow sections of the distribution system.

In this country, Nematodes have no public health significance, they carry no diseases, and are not human parasites. Although it is not likely known, many of the Nematodes are consumed by an individual every year in raw fruits, salads, vinegar, and perhaps even in his drinking water. They are quite resistant to chlorination and the levels normally applied for the control of pathogenic bacteria are not sufficient to kill the nematodes. In this respect, we are fortunate as this climate controls some species that are a serious human problem in the middle east and Asia.

CONTROL OF INFESTATIONS

As most of the organisms that inhabit water mains are resistant to normal Water Works sterilization procedures and as no chemicals are suitable for adding to water to control this type of nuisance organism, good housekeeping is the only effective control. As much as possible of the organic material

should be kept from the water mains. This is best accomplished through chemical precipitation and sand filtration. In laying water mains low flow areas should be eliminated as much as possible, as these provide a refuge, and where dead ends occur they should be flushed routinely. In this way, it will be possible to maintain the confidence of the consumer in the products that you deliver.

CONCLUSION

This lecture has only touched very lightly on the high spots of this subject. Future courses will provide further and more detailed information. In the meantime, for those interested in learning more on this subject, a book recently published by the United States Public Health Service is well worth your reading and cannot be too highly recommended. The title is Algae in Water Supplies, by Mervin C. Palmer. It is available from the Superintendent of Documents, U.S.Government Printing Office, Washington 25, D.C. for the price of $1.00

As the operator can hardly be expected to be a competent Biologist, Chemist, mechanic and gardener, problems in the identification of unknown organisms arise from time to time. It is the intention of this laboratory and certainly the Biology Section to assist wherever possible. In this regard, consultative and identification services are available and provided to the limit of the capabilities of our small staff. If specimens such as insects, algae, etc. are to be sent for identification, it is important that they be preserved. Formaldehyde is cheap and effective and can be purchased from any drug store. If the sample is put in a solution of about 5% formaldehyde and 95% water, it will be assured of arriving in good condition.

TASTE AND ODOUR CONTROL

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To-day's consumer is likely to be very critical about the taste in the water he drinks or the odour of the water he uses for his personal hygiene. He has become very conscious of good water quality and would detect very quickly any unusual tastes and odours. He is bound to complain if any disagreeable flavours were to develop in the water. Therefore, the waterworks operator can no longer just brush aside any complaints with statements that the people will become accustomed to the tastes and odours or that they will get tired of complaining; but, instead he must seek better methods of treatment which would help to improve the palatability of water from his plant.

Most people tend to associate bad tastes and unusual odours with poor quality water. If these objectionable conditions are not corrected immediately or allowed to occur too often, some persons may begin to have serious doubts about the competence of the operator at the waterworks. The public water may be of the highest quality as far as clarity and purity are concerned, but if it is not very palatable, it would be almost impossible to attract any tourists or to encourage any new people or new business to settle down in the community. Therefore, the waterworks operator should be aware of the fact that good taste is just as important as safety and cleanliness in public water supplies.

This lecture is intended to show how taste and odour problems develop in water supplies and to outline some of the methods for controlling them.

TASTES

There are only four true taste sensations: sweet, sour, bitter and salty. All other apparent senses which are commonly referred to as tastes are actually odours, even though the sensation may not be noticed until the material has been taken into the mouth.

ODOURS

Unlike the tastes, there are no definite numbers nor classifications of odours. A table on the following page gives qualitative descriptions of some of the more common odours that are prevalent in water supplies. It can be used as a guide to classify the type and to determine the source of odour.

SOURCES OF TASTES AND ODOURS

Causes of tastes and odours in water supplies can be classified into two general categories: natural and man-made. Among the natural causes are algae, aquatic plants, decaying vegetation, actinomycetes, nuisance organisms and slime growths; and the man-made causes include industrial wastes and sewage.

NATURAL CAUSES

1) Algae Algae are considered to be the most important source and the most frequent cause of objectionable tastes and odours in water. Practically every water supply which is dependent on a stream, river, lake or any other surface waters, is likely to encounter taste and odour problems that are associated with algae at one time or another. These problems are generally seasonal. They may occur during late spring, early or late summer months when heavy algae blooms take place. In some instances, they may occur during the late fall or winter months when the algae begin to die off. Severe odour conditions have been experienced where a river had frozen over solidly and become anaerobic in some areas.

A few species of algae such as Synura and Dinobryon if present in relatively low numbers can give rise to odour complaints while there are many others that give off tastes and odours which vary in type according to the local conditions and the population.

GUIDE FOR QUALITATIVE DESCRIPTIONS OF ODOURS

Code	Nature of Odour	Description (Such as Odours of:)
A	Aromatic (spicy)	camphor, cloves, lavender, lemon
Ac	cucumber	Synura
B	Balsamic (flowery)	geranium, violet, vanilla
Bg	geranium	Asterionella
Bn	nasturtium	Aphanizomenon
Bs	sweetish	Coelosphaerium
Bv	violet	Mallomonas
C	Chemical	industrial wastes or treatment chemicals
Cc	chlorinous	free chlorine
Ch	hydrocarbon	oil refinery wastes
Cm	medicinal	phenol and iodoform
Cs	sulfuretted	hydrogen sulfide
D	Disagreeable	(pronounced, unpleasant)
Df	fishy	Uroglenopsis, Dinobryon
Dp	pigpen	Anabaena
Ds	septic	stale sewage
E	Earthy	damp earth
Ep	peaty	peat
G	Grassy	crushed grass
M	Musty	decomposing straw
Mm	moldy	damp cellar
V	Vegetable	root vegetables

STANDARD METHODS, Eleventh Edition, P. 255.

Odours are said to result from oils and substances which are released by the algae during their life process and after their death. When the algae die, the cells decay and break down to form minute quantities of soluble oils which help to intensify the tastes and odours present in the water.

Some of the typical odours produced by algae are described below:

a) Aromatic: any odours which resemble a particular flower or vegetable; geranium, violet, muskmelon and cucumber; spicy: skunk-like or garlic.

b) fishy

c) grassy

d) musty and earthy: can also be described as weedy, swampy, marshy, peaty, straw-like, woody and moldy.

e) septic: foul odour somewhat like a smell of a pig-pen.

2) Decaying Vegetation - Decaying vegetation is the second most important cause of tastes and odours. All the dead plant materials such as algae, leaves, grass, weeds and any other vegetable matter can be classified under this heading. The decay or decomposition is brought about by fungi, bacteria and actinomycetes. These organisms, either through their activities or metabolism, are capable of producing substances which can impart unpleasant tastes and odours in the water.

3) Water Weeds - Certain types of water weeds and other aquatic plants cause considerable troubles in water supplies involving taste and odour problems. In areas where they grow in abundance, they can introduce significant quantities of organic matter to the water giving rise to distinct odours.

4) Actinomycetes - Actinomycetes are a class of microscopic organisms usually found in the soil. They are capable of utilizing organic and nitrogeous material that are present in dead algae and decaying vegetation. They can produce soluble and volatile substances which have strong pungent earthy odours similar to those found in compost piles.

5) Nuisance Organisms - There are a number of different types of micro-organisms that flourish in the distribution system and contribute to the taste and odour problems.

These are referred to as nuisance organisms and among these may be included:

a) iron bacteria
b) sulphur bacteria
c) sulphate-reducing bacteria
d) non-specific bacteria capable of causing iron transformations

Some of these organisms such as the iron bacteria and those that are responsible for the corrosion of iron produce slimy reddish-brown deposits on the walls of water pipes and tanks causing discoloration and turbidity in the water. These slimy deposits decompose and form substances which create foul taste and odour conditions in the distribution system.

Sulphur bacteria are capable of converting any sulphur-containing substances into either elemental sulphur or sulphates The sulphates, in turn, are reduced by sulphate-reducing bacteria into hydrogen sulphide which is a gas with an unpleasant smell of "rotten eggs".

6) Slime Growths - Slime growths appear on the walls of open channels, basins, reservoirs and in many parts of the distribution system. The main objection to the presence of slime growths is the putrid tastes and odours they can produce upon decay.

MAN-MADE CAUSES

1) Industrial Wastes - Severe taste and odour problems can be created in the water supply if it is polluted by certain types of industrial wastes. The organic substances contained in these wastes are considered to be almost totally responsible for any serious odour problems. Industrial wastes may also introduce some chemical nutrients which could stimulate the growth of objectionable organisms.

Among the industrial wastes which can produce troublesome odour problems in water supplies are those of: organic chemical plants; oil refineries; food and beverage industries; paper mills; tanneries; packing-houses; by-product coke plants and plastics industries.

One of the most troublesome substances sometimes found in these wastes are phenols or phenolic compounds. Phenols react with chlorine to form chlorophenol compounds which can cause severe taste and odour problems in water supplies at very low concentrations. Sometimes the odours from these chlorophenol compounds are detectable in concentrations as little as 2 parts per billion.

2) Sewage - Sewage contains certain types of organic substances which can lead to very troublesome taste and odour problems in water supplies. One notable example of these substances is the synthetic detergent. Synthetic detergents have gained a wide popularity in the recent years and they do not break down very readily in the sewage treatment processes. Therefore there is no reason to doubt that these substances may eventually find their way into some of the potable water supplies. Many of the detergents are made from by-products of the petroleum industry and capable of emitting very strong odours when chlorinated. Some detergents, particularly the amine types, can even produce soapy tastes and odours detectable in concentrations as low as 5 parts per million.

In addition, sewage contains many nutrients such as nitrogen and phosphorous which could stimulate the growths of obnoxious algae and other organisms.

3) Waterworks - At the waterworks itself, there are at least two conditions which can lead to serious taste and odour problems.

If the settling basins are not cleaned out thoroughly at frequent intervals, the sludge will accumulate and during the warm weather, it will decompose and impart an objectionable odour to the water. In an open reservoir or settling basin, after coagulation, the water is generally low in turbidity and therefore is in an ideal condition for algae development.

Another condition that can give rise to odour complaints is the use of improper chlorination for the disinfection of water from the plant. The natural odours of water are frequently intensified or changed in character by the use of chlorine as a disinfecting agent. The odour of free chlorine is in itself very disagreeable. If the application of chlorine is not carefully controlled, water with highly unpleasant chlorinous tastes will result.

MEASUREMENT OF TASTES AND ODOURS

Because the substances which causes tastes and odours in water supplies are so varied and are present in such small quantities, it is practically impossible to analyze and measure them. The only practical method of assessing taste and odour is to taste and smell the sample of water itself.

TASTE TEST

Taste tests should be performed only on the samples of water known to be safe. In most instances, the odour tests will be sufficient to provide the necessary information. However, there are a few tastes which cannot be detected by the odour test.

Taste tests can be made at the natural temperature of the water (about 20°C) although tests at 40°C, which is near the body temperature, would eliminate any influences due to hot or cold sensations.

The taste test can be made on the various dilutions just before the odour tests. It has been suggested that the mouth should be rinsed with warm distilled water before making the taste tests.

ODOUR TEST

There is no absolute method of measuring odour concentrations in the water samples. People react differently to a given odour intensity and even the same person will not be to consistent in the concentrations that he can detect from day to day.

There is, however, one practical method which has been devised by Spaulding and it is best suited for use in water treatment plants. It is referred to as the Threshold Odour Test. This test is done by smelling samples of odour-bearing water diluted in various proportions with odour-free water and the odours given off are compared with that from an odour-free standard. The samples are heated to either 40°C (104°F or 60°C (140°F). The dilution at which odour can just be detected is called the threshold point and this is expressed quantitatively as Threshold Odour Number.

The details for the Threshold Odour Tests can be found in the Standard Methods, Eleventh Edition, p.253.

Odour tests conducted at higher temperatures would enable the operator to detect odours far below the levels which would be noticed by the average consumer.

Definition

Threshold Odour Number is defined as the dilution ratio or the number of times that an odour-bearing water has to be diluted with odour-free water until the odour is just detectable by the odour test and upon any further dilution the odour will not be detected.

CALCULATION

$$\text{Threshold Odour Number} = \frac{\text{Vol. of sample} + \text{Vol. of odour-free-water}}{\text{Vol. of sample}}$$

For example, if the threshold point was determined when 25 ml of odorous sample was diluted to 200 ml (with 175 ml of odour-free water), then

$$\text{Threshold Odour Number} = \frac{25 + 175}{25} = 8$$

SUGGESTED DRINKING WATER QUALITY STANDARDS

The present water quality standards state that "the water shall have no objectionable taste or odour". The application of this rule will depend to a considerable extent on what a community becomes accustomed to. It is recommended that the odour levels in the drinking water should not exceed a Threshold Odour Number of more than 3.

VALUE OF THRESHOLD ODOUR TEST

At waterworks where taste and odour conditions occur quite frequently and constitute a major problem, threshold odour tests can provide very valuable information to the operator. By conducting these tests on a regular basis, preferably once a week and more frequently during the critical periods, close checks can be maintained on the odour levels in the water supply. The operator can also keep abreast of any odour developments in the water supply. He could detect any unusual odours in time to apply the necessary treatment at the plant.

Threshold odour tests are particularly useful in evaluating various methods of taste and odour control at the plant. It can also be used to determine the degree of treatment necessary to reduce the odour in the water to the levels that would satisfy all consumers.

CONTROL METHODS

There are a number of ways that an operator can cope with taste and odour problems at his waterworks. Before he considers any method of treatment, he must study the nature of his problems and investigate the facilities that he has available in the plant. He might ask himself the following questions:

A) What is the nature of the taste and odour ? Is it fishy, swampy or chemical ?

B) What do you think is the cause of the problem? Algae, decayed vegetation or phenols?

C) Does the problem occur frequently? Is it seasonal?

D) What treatment facilities do you have in the plant? Any filters? How much detention time? Any feeder equipment?

There are two general methods of attacking taste and odour problems in water-supplies - preventive treatment and corrective treatment. Preventive treatment involves those measures which would remove the source of the problems and control the environment so that tastes and odours do not have an opportunity to develop. It deals mainly with controlling growths of aquatic plants, algae and nuisance organisms. Corrective treatment is necessary when taste and odours have already developed in the water supply and cannot be controlled by preventive measures. It is usually applied in the treatment process for the specific purpose of removing any objectionable tastes and odours in the water.

PREVENTIVE TREATMENT

a) Control of weeds and aquatic plants in impounded areas and in open reservoirs.
   i) periodic cleaning programme
   ii) concrete or masonry linings on the sides and bottom of the reservoir
   iii) use of chemicals

b) Control of algae growths

i) shut out sunlight either by covering the reservoir or by using carbon "blackout"
ii) copper sulphate treatment applied directly to the water in the lake or in the reservoir
iii) chlorination
iV) application of algicides

c) Control of nuisance organisms in distribution systems

i) chlorination
ii) frequent flushing out of watermains, particularly near the dead ends.

d) Control of slime growths

i) chlorination
ii) programme of periodic cleaning

e) Good housekeeping

i) clean out coagulation and sedimentation basins at frequent intervals
ii) do not allow any sludge accumulations in the basins

f) Application of proper dosages of chlorine.

CORRECTIVE TREATMENT

Aeration - Aeration is a simple and a popular method of treatment for removing tastes and odours in municipal water supplies. Natural waters such as those found in the lower layers of lakes and reservoirs during the late summer and late winter months, in deep wells and in slow-mowing rivers during the dry-spells are generally so deficient in dissolved oxygen that the tastes may be affected. Aeration of such waters will help to improve the taste by replenishing oxygen. It will also help to reduce any free carbon dioxide and hydrogen sulphide present.

The usefulness of aeration for a complete removal of tastes and odours is limited. However, it finds its great effectiveness in waters where easily oxidizable or volatile gases such as hydrogen sulphide, are present.

Water can be aerated by one of the following methods:

1) simple exposure to air as in open aqueducts, basins and reservoirs.
2) waterfalls and flows over cascades, steps, troughs, and weirs.
3) flows through trickling devices, coke beds and perforated trays.
4) air diffusion units.
5) spray nozzles.
6) air-lift pumps for drawing water from deep wells.
7) high pressure aerators.

ACTIVATED CARBON

Activated carbon is the most widely known method for controlling tastes and odours. Carbon has the ability to remove all types of organic substances and some gases that may be present in the water. The surface of the carbon particle possesses an attractive force that enables it to draw and hold on to the molecules of various compounds with which it comes into contact. This ability of the activated carbon to attract other substances is known as "adsorption".

Besides taking out the objectionable compounds, carbon helps to stabilize sludge, improve floc formation and remove other non-odorous organics which would lower the chlorine demand.

For purification of potable water supplies, activated carbon in the powdered form is considered to be the most economical and most efficient method of treatment. Powdered carbon can be used only in those water treatment plants that are equipped with filters which can take it out from the water before distribution to the consumer.

Because it is necessary to treat such large volumes of water with very small dosages, carbon should be applied where good mixing facilities are available. In order to derive maximum benefits from carbon treatment, water being treated should be allowed to remain in contact with carbon for at least 15 to 20 minutes.

CHLORAMINE TREATMENT

Chloramination or chloramine treatment is a process in which chlorine is added to react with applied or natural ammonia already in the water to form chlorine-ammonia compounds (chloramines).

Ammonia helps to retard the oxidizing power of chlorine and thus is slows down the formation of highly odorous chlorine compounds. Because of this, objectionable tastes and odours do not develop very rapidly in the chloramine-treated water as in chlorinated waters. Chloramines have been particularly effective in minimizing the development of severe tastes in waters containing phenols. Chloramines can be used to carry higher chlorine residuals in the distribution systems.

It is recommended that the ammonia be added to the water first and adequately diffused before the chlorine is applied so that there is no opportunity for the chlorine to combine with other organic substance to form any odour-producing compounds. The optimum weight ratio of chlorine to ammonia should be about 3:1.

SUPERCHLORINATION AND DECHLORINATION

Superchlorination is the application of chlorine in excess of that required in the initial residual and without any regard to the residual produced. It is used occasionally to destroy tastes and odours in water supplies.

In 1926, N.J. Howard and R.E. Thompson first introduced large-scale superchlorination at Toronto for controlling tastes and odours in the city water supply. To-day there are two plants in Metropolitan Toronto, R.G. Harris Filtration Plant and Island Filtration Plant, still practising superchlorination whenever severe conditions occur.

After superchlorination, the water has too much residual chlorine and may possess a disagreeable chlorinous taste. Therefore, the water must be dechlorinated to remove any excess chlorine before it can be supplied to the consumer.

Dechlorination can be accomplished by adding one of the following chemicals.

a) sodium thiosulphate $Na_2 S_2 O_3$

b) sodium metabisulphate $Na_2 S_2 O_5$

c) sodium sulphite $Na_2 SO_3$

d) sodium bisulphite $Na HSO_3$

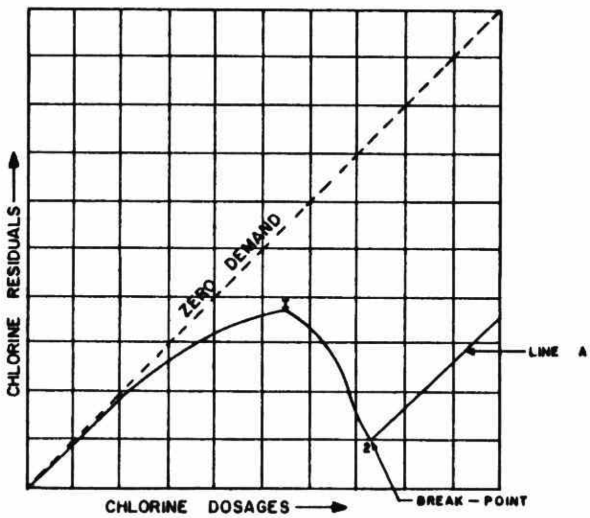
e) ammonia NH_4OH

f) sulphur dioxide SO_2

Sulphur dioxide gas, if applied in the same manner as chlorine, is considered to be relatively inexpensive.

BREAK-POINT CHLORINATION OR FREE - RESIDUAL CHLORINATION

If chlorine is added to water that has no chlorine demand, the concentration of residual chlorine should be equal to the concentration of applied chlorine as indicated by the dotted line on the graph.



TYPICAL CHLORINE RESIDUAL CURVE ILLUSTRATING THE BREAK-POINT CHLORINATION

However, if the water does have some chlorine demand and chlorine is added in increasing dosages, the relationship between applied and residual chlorine may appear as a curve indicated by line A. Point 2 on line A is called the break-point. The break-point in the chlorination of water may be defined as the point beyond which all, or nearly all of the chlorine will result in free residual chlorine almost in proportion to the rate of application.

The shape of the chlorination curve results from the fact when chlorine is first applied, the immediate chlorine demand results in the formation of some stable chlorides and unstable chloramines. Chloramines show up in the cenventional orthotolidine tests as residual chlorine. At point I on the curve, the increasing dosage of applied chlorine break down the chloramines that have been indicated as residual chlorine by the orthotolidine tests. At point 2, the chlorine demand is now satisfied and any addition of chlorine beyond this point will be indicated as true chlorine residual.

The break-point is caused by the presence of ammonia or other nitrogen compounds in the water.

Application of Break-point Chlorination

All of the waters do not present a clear-cut or a definite break-point curve as shown above. In some instances, the changes on the quality of raw water may effect rapid changes in the break -point. It has been reported that by adding very small quantities of ammonia or ammonium sulphate to the water, a recognizable break-point pattern has been obtained.

Before break-point chlorination is practised in any plant, it is suggested that laboratory tests should be made first to determine whether or not that this treatment process is practical cn that particular water

CHLORINE DIOXIDE (ClO_2)

Chlorine dioxide has been employed very successfully at many waterworks in Ontario to control tastes and odours caused by phenols and other industrial wastes.

Chlorine dioxide is very unstable. It cannot be shipped or stored in bulk and therefore must be produced as it is needed.

Chlorine dioxide can be produced in two ways:

a) sodium chlorite and chlorine water

$$2NaClO_2 + Cl_2 - 2ClO_2 + 2NaCl$$

b) sodium chlorite and acidified solution of either calcium or sodium hypochlorite

In water treatment plants, the chlorine water is supplied from gas chlorinators. The discharge line of the chlorinator is connected to one end of a reaction chamber and a solution of sodium chlorite is fed into the chamber by means of a metering pump. The purpose of this chamber is to make sure that all the sodium chlorite is converted into chlorine dioxide before it is discharged into the water supply.

In practice, excess amount of chlorine is usually added to the chamber in order to insure that sodium chlorite has been completely reacted. Theoretically, 1 part of chlorine reacts with 3.1 parts of sodium chlorite however it is recommended that chlorine to sodium chlorite ratio should be not less than 1:2 more preferably 1:1.

Chlorine dioxide has 2 1/2 times greater oxidizing capacity than chlorine. Therefore it can break down the complex organic compounds such as phenols into non-odour producing substances more readily than chlorine.

RELATIVE MERITS OF DIFFERENT CHLORINATION PROCESSES

Chloramine Treatment

a) least effective in eliminating tastes and odours
b) suppresses any development of chlorophenolic tastes
c) able to sustain longer chlorine residuals in the distribution system
d) excess ammonia can encourage growths of nuisance organisms

Break-point Chlorination

a) can be used to great advantage where ammonia and nitrogen organic compounds are present
b) good taste and odour control method
c) requires careful control to insure addition of sufficient chlorine
d) inadequate chlorination can intensify tastes and odours

Superchlorination and Dechlorination

a) effective in plants where there are short detention periods
b) if water quality fluctuates, this method of treatment insures chlorine dosages above the break-point

c) large amounts of chemicals required for chlorination and dechlorination

Chlorine Dioxide

a) destroys most organic compounds
b) effective against chlorophenolic tastes
c) sodium chlorite is expensive
d) careful control required in maintaining proper ratio of chlorine to sodium chlorite
e) some doubts about its ability to control tastes and odours due to paper mill wastes and algae growths.

POTASSIUM PERMANGANATE

Potassium permanganate, like chlorine, is another oxidizing agent. It will partially oxidize and break down organic compounds into substances which do not undergo any further reaction with chlorine to form any odorous compounds.

At a number of waterworks in the United States, potassium permanganate treatment has been found to be very effective for controlling and odours produced by algae, actinomycetes, decayed vegetation and industrial wastes. In 1963, experiments with potassium permanganate were conducted under the guidance of OWRC at waterworks in Chatham and Peterborough. Plant scale tests indicated that the taste in the water had improved greatly after treatment with potassium permanganate dosages less than 1 part per million.

Potassium permanganate has now been adopted for conditional use at Chatham waterworks whenever severe taste and odour problems occur. At Peterborough, this method of treatment was not recommended because the waterworks did not have the proper facilities to obtain the maximum benefits from potassium permanganate.

Two basic requirements in the plant must be met before the use of potassium permanganate can be considered: good filters and adequate detention time.

a) Since potassium permanganate itself forms an insoluble manganese oxide hydrates upon reduction, the water works must be equipped with good filters to remove them. If any unreacted potassium permanganate or manganese compounds are allowed to pass through the filters into the distribution system, it can lead

to troublesome staining problems.

b) A contact time of at least one to one and one-half hours is required between the time of application in the rapid-mix and the time to reach a point located about three-quarters ($\frac{3}{4}$) of the way through the sedimentation basins. This means that the characteristic pink colour of potassium permanganate should persist up to that point for a period of at least one to one and one-half hours. This colour zone should disappear at this point. The dosage of potassium permanganate must be properly regulated so that the pink colour does not show up on top of the filters.

As potassium permanganate oxidizes organic compounds, it loses its characteristic pink colour and forms brown insoluble manganese oxide hydrates. The bulk of the manganese oxide hydrate can be removed by alum coagulation and sedimentation while the remaining traces are removed by the filters. For this reason, it is desirable to have good flocculation and sedimentation basins in the plant to insure a complete re-action of the potassium permanganate before it reaches the filters.

OZONE

Ozone is another method of treatment which has been used extensively in Europe and in British Isles for disinfection of water supplies and in some parts of United States for taste and odour control.

Ozone is faintly blue gas with a pungent odour. It is made in a closed apparatus known as an ozonator where a high voltage current is discharged through a dry atmospheric air. During the process, some of the oxygen molecules (O_2) are converted in ozone molecules (O_3) . Each ozone molecule contains 3 atoms of oxygen. Because of its instability, ozone breaks down very readily to normal oxygen and nascent oxygen. The latter is a powerful oxidizing agent, ready to combine with any oxidizable material either in the air or water.

Advantages

a) rapid sterilizing effect on water
b) ozone removes colour and also improve tastes and odours

Disadvantages

The cost of equipment for employing ozone is considerably much higher than the installations for chlorine.

GRANULAR ACTIVATED CARBON FILTERS

Granular activated carbon filters are essentially pressure type of filters with a bed of granular activated carbon supported on layers of gravel. In this treatment process, the water is first clarified by means of sand filters and then passed through the carbon filters to remove any tastes and odours.

There are not very many municipal water treatment plants of this type simply because it has been demonstrated that powdered activated carbon can be used more economically and more efficiently for purifying municipal water supplies. However, there are a few plants in California, Michigan and Wisconsin where occasional surges of severe odours are encountered and cannot be controlled adequately with prevailing dosages of powdered carbon.

Carbon filters have been used extensively in bottling plants and food industries where the consistency in taste and odour quality of the water is of prime importance.

SUMMARY

None of these methods are applicable to the removal of all tastes and odours and no one method will be suitable to all waterworks. Each operator must study his own problem, consider the facilities he has available and then decide on the treatment which he thinks is the best suited for his own particular plant.

OPERATION AND MAINTENANCE OF PUMPS AND MOTORS

A. B. Patterson
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PUMP OPERATION

Pumps, like people, act differently under different conditions. To select pumps intelligently and operate them efficiently requires an understanding of what may and may not be expected of them.

In order that you may all understand the basic fundamentals of centrifugal pumps, I propose to have you prepare a characteristic curve for a typical centrifugal pump using test data which is provided.

(At this point all candidates prepared a Head-Capacity Curve)

Now we have a simple graphic form a picture of what will happen under any specified condition. The data for this curve must be carefully measured by an actual test and is always available from the manufacturer. As pump operators, you should know where these curves are and how to use them.

The pump we are considering is one of constant speed. As operators you are aware that it is sometimes necessary to change the discharge pressure or head against which this pump must

operate. Such changes may be brought about by any one of the following conditions:

(a) Installation of a new and larger feeder main from the pumping station resulting in lower back pressure.

(b) Installation of a new tank or reservoir into the pumping district with a resultant change of head.

(c) Installation of additional pumping cpacity into a station resulting in a greater back pressure or pump head.

We would expect that the engineers or suppliers would be called in to help with this problem, but I feel that as operators you should know the basic facts and be prepared to enter into an intelligent discussion. This is not difficult. Three simple rules are involved, and I would suggest that they be committed to memory. They are:

(1) Capacity of a unit varies directly as the impeller diameter ratio.

(2) Head varies directly as the (impeller diameter ratio)^2.

(3) Power varies directly as the (impeller diameter ratio)^3.

A simple way to remember these is to arrange the three key words in alphabetical order and then number them - 1, 2 and 3 - as follows:

1 - Capacity
2 - Head
3 - Power

Returning now to the characteristic curve data, we note that a capacity of 4,000 G.P.M. the unit will operate at a head of 140 ft., an efficiency of 87%, and consume 163 brake H.P.

Assuming that the new impeller diameter will be 11.5 inches as compared with the existing impeller diameter of 12 inches, we are now able to predict the new pump characteristics at the reduced impeller size.

The basic ratio is -

$$\frac{\text{New Capacity}}{\text{Old Capacity}} \quad \text{as} \quad \frac{\text{New Impeller Diameter}}{\text{Old Impeller Diameter}}$$

We know three of the four values; therefore, let X equal the unknown and we can easily solve for X.

Capacity: Let X = New Capacity resulting from the smaller Impeller diameter.

$$\frac{X}{4000} = \frac{11.5"}{12.0"}$$

$$X = \frac{11.5}{12} \times 4000 = 0.958 \times 4000$$

$$= 3{,}832 \text{ G.P.M.}$$

Head: Let X = New Head resulting from the smaller Impeller diameter.

$$\frac{X}{140} = \frac{11.5"^2}{12.0"}$$

$$X = \frac{11.5^{\ 2}}{12.0} \times 140 = 0.918 \times 140$$

$$= 129 \text{ ft.}$$

Power: Let X = New Horsepower requirement resulting from the smaller Impeller diameter.

$$\frac{X}{163} = 11.5"^3$$

$$X = \frac{11.5^3}{12.0} \times 163 = 0.879 \times 163 = 143 \text{ B.H.P.}$$

To sum up, we now know that an impeller reduced from 12.0 inches in diameter to 11.5 inches in diameter will change the pump characteristics as follows:

Capacity from 4,000 G.P.M. to 3.832 G.P.M.
Head from 140 feet to 129 feet.
Power requirement from 163 B.H.P. to 143 B.H.P.

The efficiency, for all practical purposes, will remain the same.

PUMP INSTALLATION AND OPERATION

(1) Pump Piping

Never use pipe smaller than the pump nozzles, and preferably use larger, especially on the suction side. Use eccentric reducers from the larger suction pipe to the pump nozzle to prevent formation of air pockets in the pipe. Suitable tapered reducers on the suction and increasers on the discharge will ensure efficient flow on the system and conserve power. Run all piping as directly as possible and with a minimum of elbows and other fittings.

Never place a pipe-line elbow in a horizontal plane directly at the pump suction nozzle. Between the elbow and the suction nozzle, use a piece of straight pipe at least four to six pipe diameters long. An elbow attacted in a horizontal plane directly at the pump suction tends to cause unequal thrust and hydraulic losses due to the liquid filling one side of the suction chamber and impeller eye more than the other.

Whenever possible the suction reducer and the discharge increaser should be installed directly on the pump nozzles. This produces better conversion of flow velocity and reduces hydraulic losses that might be caused by valves or elbows directly at the pump suction, and that might affect the pump efficiency.

Plan and install the suction line so that air pockets cannot form in it. A tight suction line is essential for proper operation of any pump. Air leaking into the suction line gets into the pump, reduces its capacity, and may cause it to stop pumping. A small air leak in the suction will cause trouble in any centrifugal pump.

Install a gate and a check valve on the discharge line close to the pump. Put the check valve between the pump and gate valve and the tapered increaser between the pump and check valve. The check valve protects the pump against excessive surge pressure and also against reverse rotation.

When the capacity of a centrifugal pump must be controlled by throttling, always use the discharge valve.

(2) Priming Centrifugal Pumps

No centrifugal pump of the usual type will start pumping properly until it has been satisfactorily primed. Satisfactory priming requires that all air must be removed from the pump, and that the pump be completely filled with the liquid. Never attempt to prime a centrifugal pump while it is running. It

is necessary that the pump be at a standstill while it is being primed. Under no circumstances should a pump be operated without being completely primed.

(3) Direction of Rotation

A pump should never be run in reverse rotation. Since it is sometimes difficult to determine the rotation of polyphase alternating-current motors in advance of operation, it is necessary to try them out for proper rotation before connecting them with the pump.

(4) Packing

Do not have the packing too tight. Unduly tight packing increases power consumption and causes rapid wear of the shaft sleeve. When first starting, back off on the stuffing-box=gland nuts until free leakage occurs. Then draw down uniformly on the stuffing-box-gland nuts until leakage is reduced to a few drops a minute. Never tighten the packing sufficiently to prevent all leakage. A slight leakage is required to lubricate the packing and prevent scoring of the shaft sleeve.

As leakage increases during the service of the pump to where it cannot be reduced by drawing up the gland, add another ring of packing to the stuffing box. After a further period of operation if excessive leakage again occurs, which cannot be controlled by gland pressure, then all the old packing should be removed from the stuffing box, and a new set of packing rings installed. When repacking the stuffing box, if packing rings of the exact size cut to proper length are not available and it is necessary to cut the rings from coil packing cut the required rings so that the joints are flush. When installing the rings in the stuffing box, make sure that the joints are staggered. If the stuffing box is fitted for a water seal and lanternring, be sure that this ring is in the proper position when installing the new packing. Check the lantern-ring position with respect to the water-seal line when the packing is compressed.

(5) Wearing Rings

Wearing rings are fitted into the casing, and frequently on the impeller, at the inlet from the suction chamber, to reduce leakage from the discharge to the suction. These wearing rings have a small clearance and depend upon the liquid in the pump for lubrication. They will eventually wear, and the

leakage will increase from discharge to the suction. Rate of wear of these rings depends principally upon the character of the liquid being pumped. Since the efficiency of the pump is lowered as the leakage past the rings increases, they should be replaced before they become badly worn.

(6) Pump Casing

Efficiency of a centrifugal pump is affected by many factors. The transition from energy of motion to pressure energy takes place within the casing. It, therefore, follows that a smooth transition is necessary for minimum losses. To this end the inside casing of the pump must be as smooth and regular as possible. Routine maintenance must be performed once every two years on all internal water passages, wire brushing, chipping, scraping and final polishing, followed by two coats of good quality paint is an essential for high efficiency.

MAINTENANCE OF ELECTRIC MOTOR

An electric motor is the most important type of machine used for driving rotating equipment like centrifugal pumps for reasons of costs, simplicity of operation and ease of maintenance.

The most common type of motor for centrifugal pump operation is the squirrel cage induction motor.

Compared to a gas engine with hundreds of moving parts, the induction motor has only one moving part, the rotor. Maintenance of the rotor bearings if of the oil sleeve journal type is the most important and the most frequent.

Another important maintenance requirement of electric motors concerns heat.

In this discussion, consider a common induction motor rated as follows:

200 H.P., 3 phase, 60 cycles, 1185 R.P.M.

The efficiency of the motor is 94 per cent
The power input = 200 ÷ .94 = 212.8 H.P.

Power losses due to the resistance in the windings and friction, etc., account for 6 per cent of the total power input

or 212.7 x.06 = 12.8 H.P.

This power is unable to perform useful work, and is converted to heat. To illustrate, how much heat is developed, if the heat losses from this motor were applied to one gallon of water at room temperature (72°F.) the water would boil in 2 1/2 minutes.

The manufacturer has designed the motor to remove this heat by providing ventilating ducts and fans, and has protected the windings against an allowable quantity of heat by use of such materials as mica and glass.

However, if dirt and dust are permitted to build up on the windings and clog ventilating passages, the machine will not be able to waste sufficient heat and the ensuing temperature rise will reduce the efficiency of the motor gradually to the point of insulation breakdown and possible machine failure.

To prevent this, the atmosphere in the pump room should be cleaned by an electrician once a year.

MAINTENANCE OF MOTORS

(1) Keep dust removed, Dust insulates windings against the loss of heat thus interfering with proper coiling; a mat of dust will retain oil and moisture. On slip rings and commutators,dust causes wear and poor electrical contact. Wipe off housing and rings regularly, and blow the dust from the windings with a clean air jet (never above 40 psi.pressure) or hand bellows. Keep oil cups closed to prevent access of dust to bearings.

(2) Keep free from stray lubricating oil. When oil-soaked, the insulation is softened and liable to burn out. Good contact is impossible with dirty commutators or rings. Oil and dust deposits are removed by carefully scraping, or wiping with a solvent like carbon tetrachloride. Avoid soaking the insulation. Never lubricate oil ring reservoirs while motor is running, as overfilling and spread of oil may follow when the motor is stopped.

(3) Keep motor as dry as possible. If a megger test shows a low insulation resistance due to moist conditions, the motor may be dried by passing a low voltage current through the windings with the armature locked stationary. A fan to blow

air through the windings aids evaporation. During long idleness, cover the motor with a tarpaulin and keep dry by the heat from a couple of light bulbs. When flooded, a motor may be reconditioned by controlled oven baking, by infra-red rays, or by a bath in hot paraffin.

(4) Keep bearings properly lubricated according to manufacturer's recommendations. Bearings should be inspected at least weekly. Oil rings in sleeve bearings should rotate freely with the shaft.

(5) Keep commutator or slip rings smooth. Good operating condition is indicated by a clean, polished brown color; a bluish color signifies overheating. If worn in grooves, resurface by means of a commutator stone; never use emery cloth nor an emery stone. Reset brushes or renew them if more than half worn. Check brush pressure and clean brush holders if dirty.

(6) Do not overload the motor. The resulting heat may melt soldered connections and bake the insulation. Overload protection is obtained by an overload relay or proper sizes fuses.

TYPICAL CENTRIFUGAL PUMP DATA

SPEED OF 1200 R.P.M.

IMPELLER DIAMETER - 12 INCHES

G.P.M.	HEAD (FT.)	EFFICIENCY	B.H.P.
1000	164	47	88
*2000	160	71	113
3000	152	83	139
3500	147	86	151
*4000	140	87	163
4500	130	86	171
*5000	118	83	180
5500	100	77	180
*6000	72	66	165

CAPACITY: $\frac{\text{New Capacity}}{\text{Old Capacity}}$ as $\frac{\text{New Diameter}}{\text{Old Diameter}}$

Therefore $\frac{X}{4000} = \frac{11.5}{12}$

Cross Multiply and Solve for X

$X = \frac{11.5}{12} \times 4000 = 0.958 \times 4000 = 3{,}832$ G.P.M.

HEAD: $\frac{X}{140} = \left[\frac{11.5}{12}\right]^2$ Therefore $X = \left[\frac{11.5}{12}\right]^2 \times 140$

$X = 0.918 \times 140 = 129$ feet

POWER: $\frac{X}{163} = \left[\frac{11.5}{12}\right]^3$ Therefore $X = \left[\frac{11.5}{12}\right]^3 \times 163$

$X = 0.879 \times 163 = 143$ B.H.P.

January, 1964.

DISINFECTION OF WATER SUPPLIES

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INTRODUCTION

The disinfection of water handling equipment, newly constructed or repaired, must be effected before such appurtenances contact potable water. Disinfection is required to protect the health of the consumer and prevent various water supply nuisances. The subject will be handled under two general headings:

(a) Disinfection of Equipment Before Service

(b) Disinfection of Operating Equipment.

DISINFECTION OF EQUIPMENT BEFORE SERVICE

GENERAL

Before placing equipment, which is to contact potable water in service, it should be thoroughly disinfected. The efficiency of this step is of great importance where unchlorinated supplies or large distribution systems are concerned. Where the chlorine residual of the contacting water is zero, or very low, the potable water could be re-infected in improperly sterilized mains. Appurtenances close to a chlorinated source may actually be disinfected by routine chlorination.

Nevertheless, this type of disinfection is not fully assured and therefore not a substitute for pre-disinfection.

Disinfection is carried out for two reasons. The first and main reason is for the destruction of pathogenic micro organisms. A second reason is for the elimination of non pathogenic micro organisms that can cause colour, odour, and taste problems.

PIPE LINE DISINFECTION

Pipe Cleaning

Chlorine is considered as a surface contact disinfectant. Therefore, the area to be sterilized must be clean. During construction, the pipe should be kept dry, and a tight fitting plug provided at the end to keep out foreign matter. Lengths of pipe having soiled interiors should be cleansed before use. One method of removing stray clumps, of soil and other debris during construction is to drag a brush made by bunching sufficient mop heads, by a rope through the pipe, keeping a length or two behind the end.

Never leave an open pipe end unattended. Small animals have been known to crawl inside a main and have become trapped. If they are jammed against a valve or constriction it may be necessary to remove several lengths of pipe to free the main of the dead animal.

If ground water is a problem in the trench, a water tight plug should be inserted in the pipe end. The ground water will carry mud and it may be contaminated by sewage from severed laterials. If allowed in the pipe or main it will leave a layer or coating of material in the bottom of the pipe. In such a case several attempts may have to be made to disinfect the main.

Before disinfection is attempted, the repaired or new main should be thoroughly cleaned. This is effected by opening available drains and hydrants until the water runs clear. A velocity in the main of 3 f.p.s. has been suggested as a desirable minimum during the flushing. All ends must be flushed in this programme.

Disinfection

The usual disinfectant in the water works field is chlorine.

This can be obtained in many forms, HTH 70% (calcium hypochlorite), HTH 15%, liquid sodium hypochlorite, and in the pure gaseous or liquid state. The form of product chosen will depend on the size of job and the equipment available. The most economical form, not considering dispensing costs, is the pure liquid or gas product. In new water works systems equipped with gas chlorinators, the distribution system could be economically disinfected using the gas product. On repaired sections and isolated additions the installation of gas equipment is seldom economically possible. The liquid solution application of other forms of chlorine is then used. The greatest percentage of main disinfection is effected using hypochlorite products.

The chlorine strength required for disinfection varies with time. For 24 hour retention a 50 ppm chlorine residual is recommended. When the disinfection carrier has a high chlorine demand this must be allowed for to ensure an adequate residual. A half hour retention period would require a 150 ppm application.

SAMPLE CALCULATION:

Pipe Line = 1 mile of 8 inch main
= 11,500 I.G. liquid volume

Chlorine required for 24 hour retention
$= 50 \text{ ppm} \times 11{,}500 \times 10^{-5}$
= 5.75 pounds of chlorine

HTH 70% required (allow 25% loss)

$$= \frac{5.75 \times 10^4}{70 \times 75}$$

= 11.0 pounds of HTH 70%

Sodium hypochlorite, 10% solution (allow 25% loss)

$$= \frac{5.75 \times 10^4}{10 \times 75}$$

= 77 pounds or 7.7 I.G. of 10% solution.

The disinfecting solution is added as the flushing water is displaced. The various end valves and hydrants are operated until the chlorine residual shows. The flushing is started near the feed source gradually working towards the ends. An even

disinfectant application is necessary. The solution can be fed to the main near the filling valve via a corporation cock. The chlorine residual can be determined by using litmus paper or orthotolidine testing solution. Using the O.T. test a deep red colour will indicate a strong chlorine residual but for more accurate determination a dilution method will be required to bring the O.T. test below 1.0 ppm.

Various liquid solution feeders and injectors are available for applying disinfectant. Large municipalities should have such equipment on hand while smaller municipalities must rent or borrow the necessary feeders.

The practice of leaving HTH tablets in the main during construction so that the necessary chlorine residual is obtained when the system is flooded should be used with care. This method of disinfection prevents prior flushing and cleaning. When the lines are filled all tablets may be washed to the far end. The tablet method of disinfection might be satisfactory on small sections of main.

For effectual disinfection the packing must be free from contamination. Jute is best disinfected by spreading it out on a clean floor and dusting on HTH powder. Soaking in 1% available chlorine solution is satisfactory, provided the fibres are dried before ramming in the joint.

Bacteriological Tests

After disinfection the strong chlorine solution is flushed to waste and bacteriological samples are collected. Do not test until the chlorine residual is zero or at the level of the normal treated water. When satisfactory test results are obtained the system may be placed in service. Further samples should be collected when the mains are in use to confirm the effectiveness of the disinfection programme.

STORAGE TANK DISINFECTION

As with pipelines the storage tank must be cleaned before disinfection is attempted. All dirt, scale, and other loose material must be removed.

Disinfection can be accomplished by spraying a strong 250 ppm chlorine solution on cleaned surfaces. In using this method make sure the tank is adequately ventilated before entering. Wear a mask with an outside source of air, such as a bottled air supply, and protective clothing during the work, including goggles.

A second method of disinfection which is satisfactory for small tanks is to fill the tank with a 50 ppm chlorine solution. In sterilizing pressure tanks make sure that all air is removed so that all surfaces are contacted. The retention time as in the case of pipe lines is 24 hours. The strength could be reduced if a longer retention period is utilized. Untouched wall surfaces above the water line and ceiling should be brushed with a strong chlorine solution.

Bacteriological samples are collected when the sterilizing solution has been fully removed. The chlorine residual should be zero or that of the supply. As per the pipe lines the tank contents should be samples from time to time.

DISINFECTION OF WELLS

Equipment contacting a potable water; pumps, casings, drop pipes, and other well appurtenances; must be disinfected before being placed in service. As well water is seldom chlorinated on a routine basis the primary disinfection is most important.

Before installing drop pipe and pump, remove all surface mud and debris. When pump is installed, apply a chlorine solution to obtain a 50 ppm chlorine residual in the well. Operate pump to obtain a strong residual at the end of the newly constructed distribution feed line. Where a long line is involved, add chlorine solution slowly while pumping from well. Retain the heavy solution in system for 24 hours.

Is is advisable to return the heavily chlorinated water back down the well between the casing and drop pipe, when applicable, during the first 30 minutes of pumping, to wash down and disinfect the inside of the casing insofar as possible.

Adverse bacteriological tests should be followed by redisinfections. Continued adverse tests may be attributed to ground water contamination and not contamination by well equipment.

DISINFECTION OF OTHER APPURTENANCES

Meters, short lengths of pipe, valves and other appurtenances, can be disinfected with one percent chlorine solution for a short contact time. Meter parts should not be overly exposed. The

solution can be brushed on thoroughly cleaned surfaces if soaking is not practical.

DISINFECTION OF OPERATING EQUIPMENT

PROBLEMS ENCOUNTERED

Disinfection of operating equipment is required when adverse tests indicate system contamination. Contamination by bacteria of intestinal origin may be indicated when tests indicate the presence of coliform micro-organisms. Taste and colour problems develop which may indicate the presence of iron bacteria and associated sulphur splitting bacteria.

A red water problem is caused by concentrated quantities of oxidized (ferric) iron. Sudden flow reversal or velocity change in the main will disturb settled iron which is then discharged to adjacent consumers. Minute quantities of iron, from the water source or the distribution system itself, can be concentrated by plain sedimentation of oxidized floc, or by iron bacteria. When iron bacteria are to blame a disinfection programme is called for. Also the absence of oxygen, especially in dead ends, will favour the reduction of sulphates to sulphides, which combine with iron and otherwise form odorous compounds. Where sulphides are formed a back sediment and offensive odours are very evident.

A red water problem may not be accompanied by an iron bacteria infestation. Hydrant flushings should be examined for Crenothrix and associated iron bacteria before disinfection is attempted. Disinfection will not remove iron from the system but will prevent deposition of iron by iron bacteria and the creation of iron sulphides.

DISINFECTION

The problems encountered in disinfecting an operating system are many, and varied. In general the aim is to apply a chlorine residual to infected equipment. The residual must be low enough so as not to cause chlorine taste problems and high enough to reach the infected area. The residual must be held at the infected part long enough to allow complete disinfection.

Small Chlorinated Supplies

Where a water works system is equipped with chlorination facilities at the source, the distribution system or other appurtenances can be disinfected by increasing the chlorine residual leaving this source. The primary residual is raised to, say 0.5 ppm, and hydrant flushing is carried out to obtain some residual in the infected area. The disinfection programme can be carried out for a few weeks on as bacteriological results indicate. Flushing may have to be repeated a number of times to maintain a residual in the infected area. It is noted that even trace residuals over a long period of time will be effective.

In urgent cases, such as where serious coliform contamination is encountered, higher chlorine residuals may be warranted.

Large Chlorinated Supplies

In large distribution systems it may be difficult to maintain even a trace chlorine residual without having a very high residual at the source, and/or wasting excessive quantities of flushing water. The creation of a chloramine residual is sometimes a solution. The addition of one part ammonia to three parts chlorine will create this residual which will last longer than a free chlorine residual. The disinfective power of this combined residual is greatly reduced over that of a free chlorine residual. Therefore, this change should not be made without careful consideration as to its effect on the bacteriological quality of the treated water.

When first attempting to blanket a large distribution system with a chlorine residual, taste problems may develop. Also, difficulty may be encountered in blanketing the system with even a chloramine residual. At first the oxidation and destruction of organic matter and various infestations will use up the applied residual, but after a time the taste problem should stop and the residual advance to the required areas. The end result will of course be a much cleaner distribution system.

Unchlorinated Supplies

When a water works system is not equipped with permanent chlorinator facilities, a temporary method must be devised to obtain the disinfecting residual in the infected parts. Batch

addition of a chlorine solution or the installation of a chlorinator will be required. Generally the batch addition of chlorine solution is not to be recommended. Where a storage well is available, such as a spring reservoir, a simple drip arrangement may be devised for obtaining the necessary residual. Again the chlorine residual may be maintained at say 0.5 ppm at the nearest consumer. Frequent flushing may again be needed to maintain the required residual in the infected area.

The disinfection of a distribution system serving an unchlorinated well supply may require the installation of hypochlorinator or gas chlorinator on a temporary or permanent basis.

GENERAL

Nothwithstanding the above, it is noted that every disinfection project is different and therefore it is impossible to cover every eventuality that may be encountered. In difficult instances, the interested regulatory body can be consulted for guidance.

REFERENCES

1. OWRC Senior Water Workd Operators Course No. 1, Disinfection of Mains.

2. Manual for Water Plant Operators, A.A.Hirsh Chemical Publishing Company Inc.,212 Fifth Ave.,N.Y. 10 N.Y.

3. Enviromental Sanitations, Joseph A.Salvato, John Wiley & Sons.

LABORATORY PROCEDURES

F. A. Voege
Director of Laboratories

In conducting laboratory tests in a water treatment plant there are general precautions that should be observed. Water samples should be representative of the whole volume passing the sampling point at the time of collection. Samples that are turbid should be collected throughout the cross section of the stream or basin. If collecting well water for dissolved gas analyses, the sample should be taken from the well with a minimum of aeration and not at the discharge end of the delivery pipe. Certain tests such as for carbon dioxide, dissolved oxygen, dissolved iron, pH, residual chlorine and phenolphthalein alkalinity should be run immediately after collection of samples.

If a sample is turbid and a color test is to be run, the sample should be cleared. Filtration or centrifuging is used depending on the test to be run. For tests involving the production of a color, filtering the sample through a porous cylinder of diatomaceous earth called a Berkefeld filter candle is probably the best method. For pH and phenolphthalein alkalinity only centrifuging should be used since filtration alters the results.

Laboratory glassware should be kept clean and washed and

rinsed after use. A closed cupboard is important for storing laboratory glassware especially in plants where the dust from chemicals being dosed may be floating in the air.

If it is necessary to weigh out chemicals for standard solutions used in filtrations or color standards, a good analytical balance that will weigh to the fraction of a gram required should be used.

In many tests, various pieces of laboratory glassware are used. The buret, and pipette are the most common pieces used for measuring out standard solutions or indicators. The buret is graduated and the pipettes may be, so that a known amount of solution has been added to the sample under tests. The graduate is a large cylinder used mainly for measuring out samples. This equipment should be read at eye level and the reading should be taken at the bottom of the concave shadow, or meniscus in the tube.

CHLORINE RESIDUALS

Since obtaining and preserving for a certain time a chlorine residual in the water being treated is a very important function in a water works plant using a surface water as the source of supply, the test of this chlorine residual is very important.

Chlorine in water may be present as free available chlorine, or as combined available chlorine both of which may be present simultaneously.

Some oxidizing agents, including free halogens such as bromine, iodine, other than chlorine will appear quantitatively as free chlorine; chlorine dioxide will also.

There are various methods in use and their use depends on the different conditions that are prevailing in the water sample. These methods are:

Iodometric -

This method is employed as a standard. It is also suitable for determing high chlorine residuals and is more precise than the orthotolidine method when the residual chlorine concentration is greater than 1 mg/l.

Orthotolidine -

This method is widely used for routine measurement of residual chlorine in plant control and in the field.

Orthotolidine Flash Method -
Is a qualitative method for free available chlorine.

Orthotolidine-Arsenite Method -
This differentiates between free available chlorine, combined available chlorine and color due to interfering substances.

Drop Dilution Method -
This is used for field use but is not accurate.

Amperometric Titration Method -
Appears to be one of the most accurate available for the determination of free or combined available chlorine.

In all these tests it must be remembered that chlorine in aqueous solution is not stable and the chlorine content in samples or solutions will decrease; especially so in weak solutions. The reduction of the chlorine present will be accelerated by exposure to sunlight, strong light or agitation. Samples to be analyzed for chlorine cannot be stored, therefore analysis should be started immediately after sampling.

For this basic course, since it is the most common method in use, only the ORTHOTOLIDINE METHOD will be discussed. This method measures both free and combined available chlorine.

There are a number of conditions that must be met so that the results will be accurate for this method: (1) The solution must be at pH 1.3 or lower during the contact period; (2) the ratio by weight of orthotolidine to chlorine must be at least 3:1; and (3) the chlorine concentrations must not exceed 10 mg/l (ppm).

In purchasing the orthotolidine reagent it is better to specify orthotolidine dihydrochloride rather than the orthotolidine base. The dihydrochloride is considerably purer and dissolves in water readily which makes the tests reagent easier to prepare.

The acid concentration in the reagent must be such that of pH of 1.3 or lower will be produced even with a sample of over 1,000 mg/l of alkalinity.

In conducting the test, the orthotolidine reagent must first be placed in the container being used for comparison and the sample added to it. This insures that the color development will take place at the pH 1.3 or lower and also that the ratio of orthotolidine to chlorine is at least 3:1.

Fresh orthotolidine reagent should be prepared after 6 months since occasional exposure to direct sunlight, or high or low temperatures may cause discolouration or precipitation and thus affect the readings obtained. Rubber stoppers should not be used on containers for orthotolidine since a reaction may occur between the rubber and the reagent.

The reaction time and temperature were chosen in this method so that the maximum proportion of the combined available chlorine would be measured while minimizing loss of color by fading or increase of color due to interfering oxidizing agents such as nitrite, ferric and certain compounds formed by chlorine with organic matter.

Various substances cause interference with the orthotolidine chlorine test and increase the apparent residual chlorine content of the sample. These interfering substances are nitrite, ferric compounds, manganic compounds, and possibly, algae.

If interfering substances are present the orthotolidine-arsenite method should be used.

APPARATUS

All readings should be taken by looking through the samples against an illuminated white surface. The surface may be opaque and illuminated by reflection or may be an opal diffusing glass illuminated from behind. Since chlorine determinations are made both day and night in water works control, it is preferable that all comparisons be made with a standard artificial light. Two light sources are mentioned in the 11th edition of Standard Methods for Examination of Water and Waste waters. If artificial light is not provided, "north" daylight should be used for comparisons. Comparisons should never be made in sunlight.

The equipment used to measure the color developed with orthotolidine varies a great deal in this province. The different kinds are: 100 ml Nessler tubes or bottles in which the color is compared visually with standards without any other equipment; Nessler tubes in a color comparator using a disk from which the

chlorine concentrations are read directly; unknown and standards in a comparator where the two solutions being compared are side by side; color developed and colored solution is inserted into a machine that measures light transmittance on a dial. The reading obtained is then transferred to a graph for chlorine concentration.

Except for the method using the disk, good color standards are necessary. According to Standard Methods the preparations of these permanent color standards is precise and instructions stated there are explicit. Other texts use different simpler methods of making up the permanent standard solutions. The following procedure is given in Standard Methods for permanent chlorine standards.

PHOSPHATE BUFFER STOCK SOLUTION 0.5M

Dry anhydrous disodium hydrogen orthophosphate Na_2HPO_4 overnight at 110°C and store in a dessicator. Dissolve 22.86g Na_2HPO_4 together with 46.16g anhydrous potassium dihydrogen orthophosphate KH_2PO_4 in distilled water and dilute to 1 litre. Let the solution stand for several days to allow time for any precipitate to form. Filter out this precipitate before using.

PHOSPHATE BUFFER SOLUTION, 0.1M

This is a standard buffer, pH 6.45. Filter the stock solution as prepared above and dilute 200 ml to 1 liter with distilled water.

STRONG CHROMATE - DICHROMATE SOLUTION

Dissolve 1.55g potassium dichromate $K_2Cr_2O_7$ and 4.65g potassium chromate K_2CrO_4 in 0.1M phosphate buffer and dilute to 1 liter with 0.1M phosphate buffer. This solution corresponds to the color produced by 10 mg/l chlorine in the standard orthotolidine procedure when viewed through a depth of 24 - 30 cm.

DILUTE CHROMATE - DICHROMATE SOLUTION:

Dissolve 0.155g potassium dichromate and 0.465 potassium chromate in 0.1M phosphate buffer and dilute to 1 liter with 0.1M phosphate buffer. This solution corresponds to the color produced by 1 mg/l chlorine in the standard orthotolidine procedure when viewed through all cell depths.

MODIFIED SCOTT PERMANENT CHLORINE STANDARDS, 0.01-1.0 mg/l

The volume of dilute chromate-dichromate solution indicated in Table I for the range of a cell depths given are pipetted into 100-ml tubes of any uniform length and diameter or into 100-ml Volumetric flasks. The volume is then made up to the 100-ml mark with 0.1M phosphate buffer solution. These standards can be read at any cell depth up to 30 cm.

TABLE I CHLORINE STANDARDS

MODOFIED SCOTT FORMULA 0.01-1.0 mg/l

Chlorine mg/l	Chromate Dichromate Solution ml	Chlorine mg/l	Chromate Dichromate Solution ml
0.01	1	0.35	35
0.02	2	0.40	40
0.05	5	0.45	45
0.07	7	0.50	50
0.10	10	0.60	60
0.15	15	0.70	70
0.20	20	0.80	80
0.25	25	0.90	90
0.30	30	1.00	100

In using these standards and samples the color comparison tubes, cells, or bottles used in this determination should not differ in depth by more than 3 per cent. It is suggested that the top of the tubes be sealed with microcover glasses to protect them from dust and prevent evaporation.

ORTHOTOLIDINE REAGENT

This reagent is prepared by dissolving 1.35g orthotolidine dihydrochloride in 500 ml distilled water. Add this solution with constant stirring to a mixture of 350 ml distilled water and 150 ml conc. HCl.

This solution should be (1) stored in an amber bottle or in the dark; (11) protected from direct sunlight; (111) used no longer than 6 months; (1V) kept from contact with rubber;

and, (V) maintained at normal temperatures. If the orthotolidine precipitates it cannot be redissolved easily and errors can be caused by the use of solutions with a deficiency of orthotolidine caused by this precipitation.

SAMPLE COLLECTION

The sample should be collected from a point in the treatment plant that allows 15 minutes contact time from time of chlorine addition to sampling.

PROCEDURE

Use 0.5 ml of reagent for a 10-ml cell, 0.75 ml for a 15-ml cell and 5 ml for a 100-ml cell. The same ratio is used for other volumes. Place the ortholidine reagent in the comparison tube, add sample to the proper volume and mix.

If the sample temperature is less than 20°C (68°F) it should be raised to that level quickly after mixing the sample with ortholidine. This can be achieved by warming with hot water.

The color comparison should be made at the time of maximum color development. If the sample contains predominately free chlorine the maximum color appears almost instantly and begins to fade. If combined chlorine is present the color develops usually at a rate that is dependent upon temperature. The usual approximate times are 25°C - 2.5 min., 20°C - 3.0 min. and 0°C - 6 min. About 5 min. after maximum color develops, a slight fading begins. Therefore, samples containing combined chlorine should be read before fading commences and the color should be allowed to develop in the dark.

If there is a natural color or turbidity in the sample, this can be compensated for by placing an untreated sample of the same thickness behind the standard and clean water behind the sample with orthotolidine in it.

If a colorimeter or photometer is used the sample will have to be measured and then decolorized and the remaining color reading subtracted from the apparent chlorine reading to give the true chlorine residual.

TURBIDITY

Turbidity in water is caused by the presence of suspended matter such as clay, silt, inorganic precipitates, finely divided organic matter, plankton and other microscopic organisms. Turbidity causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. There is little direct relationship between the suspended solids concentration and the turbidity in a sample.

The standard method for the determination of turbidity is the JACKSON CANDLE METHOD. In this method the measurements are based on the depth of a suspension in a sample that just causes the image of a candle to become indistinguishable against the general background illumination when the flame is viewed through the suspension.

The instrument used is the JACKSON CANDLE TURBIDIMETER which consists of a standard candle supported at a definite distance below a graduated viewing tube. Certain precautions must be observed, such as trimming the wick of the candle, keeping the bottom of the tube clean of soot, eliminating all drafts and keeping the tube free from scratches.

PROCEDURE

- for turbidities between 25 and 1000 units.

The turbidimeter should be set up as described by the manufacturer. The sample should be well shaken and then approximately an inch of sample added to the tube. The candle should then be lit and the sample poured into the glass tube until the image of the candle flame just disappears from view. At this point, the bottom of the tube should appear uniformly illuminated with no bright spots. Near the end of the test it is convenient to add the sample from a pipette. This allows greater control and avoids rippling of the surface of the sample in the tube.

- for turbidities over 1000 units

In this case, the sample must be diluted below 1000 units with turbidity-free water. Each addition of dilution water should be of the same volume as the original sample. When the turbidity is below 1000 units - determined by checking after each addition

of dilution water - the reading should be taken as in the case from 25 to 1000 units and multiplied by the factor:

$$\frac{\text{total volume of dilution water + volume of original sample.}}{\text{original sample volume}}$$

The Jackson candle turbidimeter has a lower limit of 25 units. For turbidities below that a Hellige turbidimeter that has been standardized with a Jackson candle turbidimeter can be used.

HELLIGE TURBIDIMETER

This instrument uses a standardized electric lamp as a source of light. Various sizes of glass containers are marked at various depths for samples of different turbidities. These different sizes used in combination with a cover glass/plunger determine the length of the light path through the sample. An adjustable optical system allows increasing amounts of light to enter the sample from the bottom to balance the light entering from behind the sample. Graphs are supplied so that the final adjustment in the amount of bottom light admitted as read on a dial can be converted to turbidity.

PROCEDURE

The sample is shaken well and poured into a container to the mark. The cover glass/plunger is placed on the container which is then set on the mirror of the instrument. The outside bottom of the container should be wiped dry so there will not be a film of water to cause errors.

The elctric lamp is then switched on and with the dial set at zero and the door closed there should be a round dot visible at the bottom of the glass container when viewed through the eye piece. By rotating the dial the round dot should eventually merge with the rest of the bottom. The reading of the dial at this point should be transferred to the graphs to obtain the turbidity.

The dial should always be rotated in one direction until the end point is reached. If end point is doubtful the dial pointer should be returned to zero and the rotation repeated until checks are obtained. If material settles out on the

bottom of the container the sample should be slowly stirred with a rubber-tipped stirrer and new readings taken.

In removing the sample from the instrument the container should be tilted slightly to avoid picking up the mirror. Moisture on the mirror may cause it to adhere to the bottom of the glass container and it may fall off and break.

The graphs supplied are specific for a definite electric lamp and/or size of sample container. Changing of either one necessitates the use of another graph. The graphs that are supplied list the lamp and size of container with which they are to be used.

JAR TESTS

The need for tests to determine how much coagulant and other chemicals must be added to remove color and turbidity is obvious. However, it is impractical to use a water treatment plant as the testing equipment especially when the pure water of a municipality may be endangered. For this reason simulated tests using jars or other vessels were introduced. These first jar tests have been reported by some authors to have started around 1918. The early water works operators mixed their samples manually, either by shaking them or by using a hand stirrer. The first machines were used some years later and were somewhat crudely manufactured.

Jar tests can be used to investigate a number of treatments such as coagulation, softening, taste and odor control and iron removal.

A number of variables have an effect on the conduct of this test. The speed of revolution of the paddles, the duration of rapid and slow mixing, when stirring of the sample should commence, the pH of the solution, the temperature of the sample, the size of sample, and the conditions existing at the water plant in question are all factors to be considered.

One of the essentials for this test is a stirring machine. One of the most common has six places for the jars and the stirrers are driven by a rheostat-controlled motor so that the speeds of the blades can be controlled over a wide range. Other pieces of equipment necessary are jars or beakers to hold the sample and pipettes with which to dose the samples. A laboratory timer and balance would also be useful. Some means must be provided of measuring the pH and temperature of the sample.

In most plants it would be helpful if the same equipment was used each time a test is run so that the number of variables occuring is kept to a minimum.

Solutions must be made up for all of the different tests that will apply to the different types of treatment under consideration. Therefore, solutions or suspensions of coagulant, lime and activated carbon will be required.

The concentration of solutions can be adjusted to the preference of the person running the test. Generally they are made up so that 1 ml of solution or suspension added to 1 litre of the sample in the jar gives a dosage of 1 ppm. Therefore, if 1 litre of dosing solution is to be made up, one gram of material is used. Fractions or multiples of dosage, solution size or sample size necessitate adjustments in either dosing solution, concentration or volume added the sample. For example from the following table any combination can be calculated.

A	B	C	D	E
Dosage desired	Size of Sample	Volume of dose	Volume of solution	Weight of material in D
	ml	ml	ml	gm
0.5 ppm*	500	1	500	0.125
0.5 ppm	1000	1	500	0.25
0.5 ppm	1000	1	1000	0.5
1.0 ppm	1000	1	1000	1.0
0.5 gpg+	500	1	500	1.78
0.5 gpg	1000	1	500	3.56
0.5 gpg	1000	1	1000	7.125
1.0 gpg	1000	1	1000	14.25

* ppm - parts per million, pounds per 100,000 Imp.gallons
\+ gpg - grains per gallon

PROCEDURE

The water works operator should set up a procedure that closely follows the treatment in the plant if at all possible. In this way, the best result obtained in the test should indicate the best result obtainable from the plant. This particularly

applies to mixing times and rates. Once the most applicable procedure is found it should be followed every time the test is run. In time, it may be possible to develop a factor between the test results and the plant results.

It is usually a little easier to set up a wide range of dosages first and determine within what dosages the desired treatment occurs. Then the range can be narrowed down and the final dosage determined.

For coagulation tests the sample should be at least one litre and the mixing should be started before the addition of the coagulant. Then the sample is stirred at a maximum rate for a few minutes. Following this the rate is decreased to very slow to condition the floc that has formed. The plant mixing time should not be exceeded at this slow rate but the test should continue up to that point as long as improvement is noted. Some authors suggest that the settling time be as long as the plant retention time but this may be impractical. This will have to be judged but turbidity readings can be used to determine whether further settling time is necessary.

In this test it is important that every sample in the jars or beakers be given the same treatment down to the smallest detail or the results may be misleading. Samples collected for turbidity after the test should be collected at the same time. The collection of these samples should be done carefully to avoid getting the settled floc in the drawn-off sample.

Often activated carbon is to be used to remove tastes and odors and jar testing is used to determine the best dosage. In this case it is necessary to relate the contact period available in the plant to the mixing time in the jar test. To do this, the plant dosage is used in the jar test and the mixing rates are varied. The results of the odor test after the activated carbon jar tests are compared with the odor from the plant itself. These results will indicate the mixing time which is used then for further tests.

All results obtained from the jar tests are then converted to dosages that would apply in the plant.

TASTE AND ODORS

Odors may be attributed to chemical materials produced

by organic growths and to the presence of pollutants or other objectionable matter in the water. The distinction is not clear cut, as the introduction of a pollutant may greatly stimulate the growth of organisms that may produce objectionable tastes and odors. Incredibly small amounts of many odorous materials can cause tastes and odors. Experiments conducted by personnel at the Robert A. Taft Sanitary Engineering Centre at Cincinatti, Ohio, have frequently yielded a detectable odor from recovered materials in concentrations of two parts per billion and less. They say, in terms of quantities that are easier to visualize, that a single teaspoonful of pollutant can impact odor to 1 million gallons of water. Since these materials can be detected in such small quantities by taste and odor tests and are often complex, it is usually impractical and often impossible to isolate and identify the causative chemical.

Taste and odor tests are very useful in a water plant to check quality of raw and finished water, to aid in setting-up jar tests for treating a taste and odor condition, and sometimes to identify the cause so that the source can be traced.

Taste tests and odor tests are quite similar except that the water must be safe to take into the mouth before a taste test. The odor test can be run at higher temperatures and thus an increased sensitivity obtained on some samples.

In conducting both these tests it is better to use panels of five to ten people or more to overcome the day to day sensory deficiencies of a single observer and to obtain a median of all the results.

These tests should be completed as soon as possible after the collection of the sample. If storage is necessary, a 500-ml, prechilled sample should be kept refrigerated in a thoroughly clean, glass-stoppered container.

The intensity of odor is expressed by a figure representing the number of times a sample has to be diluted with odor-free water so the odor can just be detected by the odor test. This figure is called the threshold odor number. This number will vary according to the temperature of the sample during the test. For hot threshold tests, 60°C (140°F) should be the standard temperature. Odors will be detected at this temperature that might otherwise be missed and if these odors are not detectable in a cold sample, the test will indicate a

developing odor condition. Certain industrial pollutants may volatilize at the 60°C temperature, and if it is thought that a lower result is being obtained by using that temperature, a cold threshold test should be run at 40°C (104°F). Taste tests should be run at 40°C since this is near body temperature and no hot or cold sensations will be experienced.

APPARATUS

The following apparatus is necessary to run a taste on odor test:

(a) Odor flask, 500-ml glass-stoppered Erlenmeyer with a fairly wide neck. One is needed for each dilution plus two for blanks.

(b) Thermometer, 0° - 110°C (32°-230°F) chemical or metal-stem dial type. One is needed for each dilution.

(c) Graduated cylinders, capacity 10, 50, 100 and 200 ml.

(d) Pipettes, Mohr 10-ml graduated in tenths and 1 ml graduated in tenths.

(e) Glass-stoppered bottles, 500-ml to hold samples for testing.

(f) Erlenmeyer flasks, 2 litre, to hold odor-free water.

(g) Large hot plate or water bath. The hot plate should, for convenience sake, be checked for cold spots which can then be avoided when heating the samples.

(h) Odor-free water generator. This apparatus can be made out of a gallon jug. A glass tube should be bent in the shape of a sloping inverted L. The long arm of the L should reach through the neck down into an inch of clean pea-sized gravel. The space between the gravel and the shoulder should be filled with 4x10 mesh granular activated carbon. Above the activated carbon a layer of glass wool is placed. Through the neck and into this layer of glass wool a second tube is placed. This tube is bent similar to the first one but with the leg inside the jug just reaching to the glass wool. The outside portion of this second or discharge tube should extend far enough beyond the side of the jug so that the storage container can be filled conveniently. Rubber or plastic tubing should not

be connected to the discharge tube. The two tubes are inserted through a two-hole rubber stopper in the neck of the jug. If it can be fitted, the two-holed rubber stopper should be covered with aluminum or tin foil before it is inserted into the neck. This will help to decrease the surface area of the rubber exposed to the water.

ODOR-FREE WATER

This should be prepared as needed because it will absorb room odors. The tap water should be passed through the generator at the rate of approximately 1 litre per minute. Carbon fines will be washed out when the generator is first started; these fines should be discarded. Before the start of a test check the effluent from the generator from freedom from residual chlorine or odor. If not free, the carbon may need renewing.

PROCEDURE

The personnel in the panel conducting the test need not be extremely sensitive to odors but they must not be insensitive. Smoking and eating should be avoided just before the test. All strong odors and scents should also be avoided. The hands should be kept away from the neck of the flasks. If a panel is to be used for testing it is better the samples be coded by someone other than a panel member. The temperature of the samples during testing should be kept within 1°C of the desired temperature for the test.

Before the threshold number test is made the taste and odor quality should be determined. Shake 200 ml of the sample at the desired temperature, sniff the odor lightly and record the description. For tasting, 10 - 15 ml of the sample at 40°C are placed in the mouth, held for several seconds and discharged. It is not to be swallowed. Both aftertaste and taste in the mouth should be recorded. Do not taste any samples when its safety is in doubt.

In obtaining the threshold number the approximate range must be determined first. This is done by using the table following:

THRESHOLD ODOR NUMBER CORRESPONDING
TO VARIOUS DILUTIONS

Sample volume diluted to 200 ml	Threshold odor number	Sample volume diluted to 200 ml	Threshold odor number
ml		ml	
200	1.	12	17
140	1.4	8.3	24
100	2	5.7	35
70	3	4.	50
50	4	2.8	70
35	6	2	100
25	8	1.4	140
17	12	1.0	200

Add 200 ml. 50 ml, 12 ml, 2.8 ml of the sample to separate 500 ml, glass-stoppered Erlenmeyer flasks and dilute the contents to 200 ml with odor-free water. Another 200 ml of odor-free water is added to another flask to serve as reference. Heat samples and reference to the temperature decided for the test. The stoppers should be left slightly ajar to prevent any internal pressure from building up.

When the contents of the flasks have reached desired temperature, remove from the heat, shake the flask containing the odor-free water, remove the stopper and sniff the vapors. Then compare the odor in the flask containing the least amount of odor-bearing sample. If an odor is detected in this sample, further dilutions must be made. If no odor is detected, continue by smelling the next sample in the sequence until positive results are obtained. Once positive results are obtained a new set of dilutions must be made. The dilutions are made using the previous table. The dilutions range from the dilution with the first positive result in the test just made to the next lower one dilution. For example, if the first positive result was obtained with the flask containing 50 ml of odor-bearing sample, the dilution range will be 50 ml, 35 ml. 25 ml, 17 ml, 12 ml.

Samples can be presented to the panel members is sequence, or presented at random, taking care that a strong sample is not smelled at the beginning. The panel or observers should not know which are samples and which are reference blanks.

The results are recorded by a plus sign if odor is detected and a minus sign if none is noted. Sometimes results are contradictory, a high dilution may be called positive and a lower dilution negative, When this happens the threshold is considered as the point where no further contradictions occur.

pH DETERMINATIONS

pH is defined as the logarithm of the reciprocal of the hydrogenon concentration in mols per litre. From the layman's point of view pH is a measure of the intensity of the alkalinity or acidity of a water sample. The practical pH scale ranges from 0, very acidic, to 14, very alkaline. The middle value of pH7 corresponds to exact neutrality at 25°C.

METHOD OF MEASURING pH

pH can be measured in various ways, the most common being electrometrica using a pH meter. Another method is colorimetric using pH papers or pH indicators. The method using the pH meter is considered the standard.

pH papers are difficult to read and are not reliable but the test is fast and convenient. The common litmus paper can be considered as a pH paper which just indicates whether a sample is acidic or alkaline. Some pH papers cover most of the pH range, while others may only cover a much narrover range of one pH unit.

To use the pH papers, the paper is dipped into the solution being tested. The paper will change in color, the amount of change being dependent upon the pH range of the paper and the pH of the sample. If the color change indicates the lowest or highest pH of the range of the paper, the next lower or higher range respectively of pH paper should be tried. This should be continued until the color change indicates the middle of a pH paper's range or if it is at the top or bottom of a range it remains there. The true pH colors are read at the tip of the paper being used.

Using colored solutions to measure pH does not need very expensive equipment but it has serious disadvantages. Color,

turbidity, colloidal matter, free chlorine all affect colorimetric pH determinations. Both the pH indicators and the standards against which the samples are compared deteriorate. Sometimes, if a sample is poorly buffered, the pH indicator will alter the pH. It is suitable for rough estimation.

The pH indicators are used by pipetting one millimitre of indicator into a portion of the sample. The color of the sample when compared with standards for that particular indicator, will indicate the pH of the sample. If a disk is used with a comparator the sample with the pH indicator in it is placed in the comparator and the disk revolved until a match is achieved.

In using a pH meter the manufacturers instructions should be followed in every detail. These instruments are usually quite fragile and should be treated with care. Batteries should be replaced when they are exhausted to prevent corrosion inside the meter.

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INSTRUMENTATION AND CONTROLS

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INTRODUCTION

Instruments and instrumentation is well known to most of us through our contact with domestic appliances. We now have electric stoves which come on and off automatically at predetermined times. We have clock radios that start to wake us in the morning and will even automatically engage the electric coffee percolator. In fact, knowing human frailities, the clock radio will ring a buzzer 10 minutes after it has automatically started if we have not got up during the 10 minute interval. Practically all of these advances have occurred during our life time.

Instrumentation and automatic controls have been active in the industrial field as well as in appliances and luxuries for our homes. The major developments in this field have also occurred during the past 25 years.

These developments have, of course, affected the water works field. Measurement of flow, pressure, pH chlorine residual, turbidity, etc.; transmission of these measurements to control panels and the feed back of the control device has resulted in the automatic control of pumping, filter backwashing, chlorine feeding, alum dosages, etc. The result has been the production of better quality water at a price more economical than could have been realized without the "era of automation".

Automation has brought advantages to the water works field some of which are listed below:

1. A reduction in the man power required to operate water plants has resulted. This, of course, is an advantage to those paying for the supply of water (perhaps not apparent advantage to those in the field).

2. The telemetering aspect of instrumentation has resulted in centralized control. It is now possible for the operator to see what is occurring at all of the various treatment phases of the plant by viewing a panel located in his office.

3. The instruments and their companion control devices are able to detect difficulties and act on them more quickly than man.

4. More complete control of the process is afforded by the instrumentation and control.

From association with some of the automatic equipment involved in water treatment and from the general description of the application of this equipment in the field, you will realize that one hour will not be sufficient time to give you a complete understanding of the equipment and its application. However, I think that in an hour we will be able to cover some of the basics of instrumentation and control and you will have some idea of the principles involved with some of these units.

There are two main divisions with respect to instrumentation in the water works field. The first main division concerns units involved in obtaining measurements and these are referred to as primary devices. The other division involves doing something with these measurements once they have been obtained. This will include transmitting, receiving, recording and controlling units and they are referred to as being secondary devices.

PRIMARY MEASURING DEVICES

A. <u>PRESSURE MEASUREMENT</u>

Pressure is force per unit area, e.g. pounds per square inch. It is usually measured via springs, levers or manometers. A manometer measures pressure by balancing against a column of liquid in static equilibrium.

B. <u>FLOW MEASUREMENT</u>

1. Differential Pressure Type

Instruments of this type measure pressure or change of pressure to determine velocity and hence flow. Most are based on the principle that the flow of fluid through a constriction in a pressure conduit results in a lowering of pressure at the constriction. This pressure change is proportional to or reflects the velocity of the fluid flowing through the restriction.

The formula for flow through this type of unit is of

the form $h_1 = K_1 \frac{V^2}{2g}$

h_1 = change of head (and can be measured)

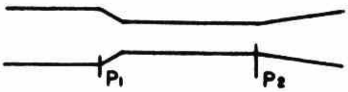
g = acceleration due to gravity

V = velocity (can calculate)

K_1= a coefficient which depends on type of meter

Once the velocity has been determined, the flow rate can be obtained by multiplying the velocity by the cross sectional area of the pipe at the point where the velocity has been determined.

Venturi Meter



K_1 = .7 to 9

$h_1 = P_1 - P_2$

accuracy good over extended period of time.

Mechanical Meters

propeller
Nutating
Chemical tracers

2. Chlorine Residual

A continuous sample of water to be tested enters a sampling cell on the device through a flow regulating valve which maintains a constant rate. An appropriate buffer solution is added to the sample ahead of the cell by means of a pump in order to stabilize the sample and eliminate any possible errors due to pH changes in the treated water. The sampling cell contains two metallic electrodes together with a grit bombardment system which abrades dirt and other foreign substances from the electrodes. As the sample flows past the electrode to waste, a direct current is generated proportional to the free chlorine residual present in the sample.

3. Turbidity

4. Colour

pH

SECONDARY INSTRUMENTS

1. MECHANICAL

Instruments of this type are operated by cables, rods, linkages, gears, etc. which are connected to pressure take-offs on primary devices. These instruments eliminate the problem of maintaining long piping which must be leak-free. The mechanical units afford much flexibility in that portions of the unit can usually be removed and replaced without disrupting the flow of the material being measured.

Disadvantages

Mechanical mechanisms are restricted in range. They depend upon the length of rods and cables etc. which becomes unwieldy as distance increases. They become heavy and bulky with many intricate connections.

These units are subject to wear and breakdown due to friction of moving parts and as a result require much lubrication.

One of the main disadvantages is that of instrument lag due to inertia and friction of the mechanical parts and slippage in the linkages.

2. PNEUMATIC

Pneumatic control generally makes use of a varying controlled-air-pressure ranging from 3 to 15 psi.

Advantages

Installation and maintenance costs are low. A continuous output signal (pressure) and extensive sensitivity to change in the variable being measured is also afforded by pneumatic devices.

Disadvantage

Limited in range to about 1500 feet. They require a clean filtered air supply, which can represent a considerable capital outlay.

An example of a pneumatic system is a force balance transmitter. With this type of unit an unknown force is balanced by one of a known magnitude. For example, the unit could be balancing the unknown force resulting from the differential pressure associated with a venturi meter (or any other primary measuring device). The difference in pressure measured by the primary measuring device, in this example a venturi meter, can be the measured and will reflect the quantity of fluid flow, etc. that we wish to have measured.

On the diagram, (fig. 3-1), the differential pressure is applied across a diaphragm. An increase in differential pressure causes the diaphragm to exert pressure on the lever which attempts to rotate in a clockwise manner. This rotation lends to restrict the flow of air through the nozzle so that an increase in air pressure results on the upstream side of the nozzle. As a result, there is also an increase in pressure on the underside of the reaction diaphragm which tends to turn the lever in a counter clockwise direction. The total movement of the lever is only of the order of a few thousands part of an inch and it is returned to its original position. However, there is now a higher pressure within the nozzle system. This pressure change is proportional to the pressurechange measured by the primary measuring device and can, therefore, be utilized as a measure of the flow through the venturi meter. This signal, the change in pressure, can be detected by a receiving device located some distance from the transmitter. For purposes of this example, the receiver could be a manometer.

There are, of course, other types of secondary pneumatic devices but this will serve as an indication of how it is possible to utilize air to transmit a signal received from a primary measuring device. This device is relatively simple and has very few moving parts. The unit, of course, is limited in range.

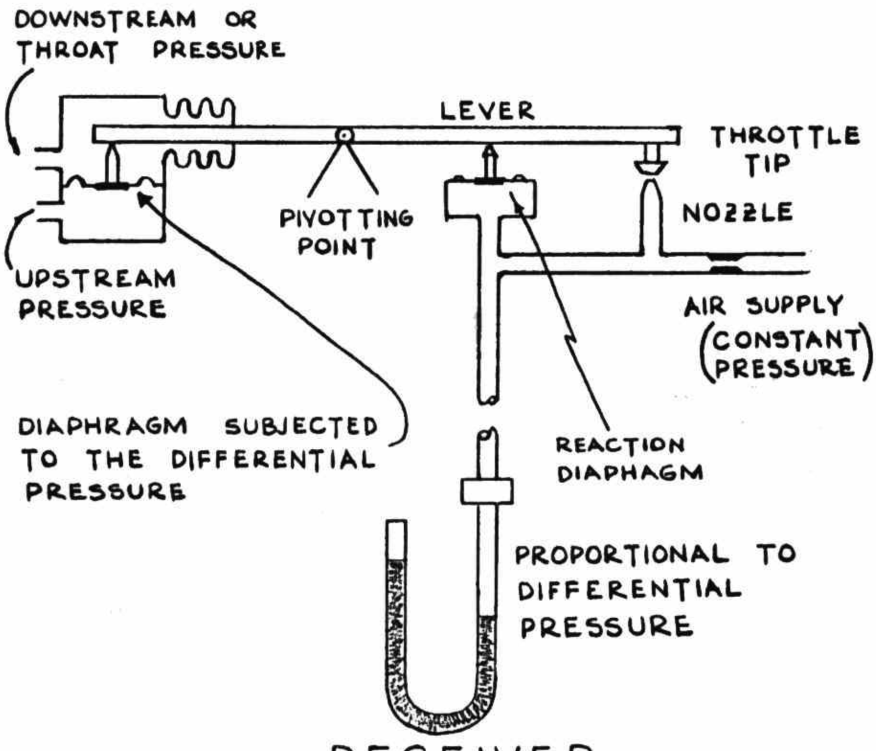
3. <u>ELECTRICAL</u>

Electronic devices have even less time lag in their response than pneumatic systems and this is of the most importance when long distance of transmissions are required. In addition, the necessity of air filtering equipment, etc. may be eliminated.

SCHEMATIC DIAGRAM OF FLUID FLOW TRANSMITTER

FIG. 8-1

FORCE BALANCE TYPE



RECEIVER

Electronic units also tend to be compact and afford the use of cabinets and central control or receiver panels.

Disadvantages

The units are usually more expensive than pneumatic or mechanical devices. They usually require skilled technicians for their servicing and calibrating.

The mechanisms commonly used to receive information from the primary devices include those using inductive balance, electrical current and voltage principle. No attempt will be made here to describe all of the methods used to obtain the information from the primary device. However, one example will help to give some indication of how such measurement is possible.

The schematic drawing, (fig. 3-4), illustrates the inductive type unit. The drawing greatly simplifies the unit involved but will give some indication of the principle of operation of the unit.

The movement of the float (it could be a diaphragm activated by air or liquid pressure) positions a magnetic core within a coil carrying electric current. The position of the core changes the electrical inductance in proportion to the position of the float or diaphragm (usually a Bourdon type tube or diaphragm which receives the differential pressure from the primary element is used.)

The receiver then consists of a unit similar to the transmitter and is used to position an indicating device such as a pointer as shown.

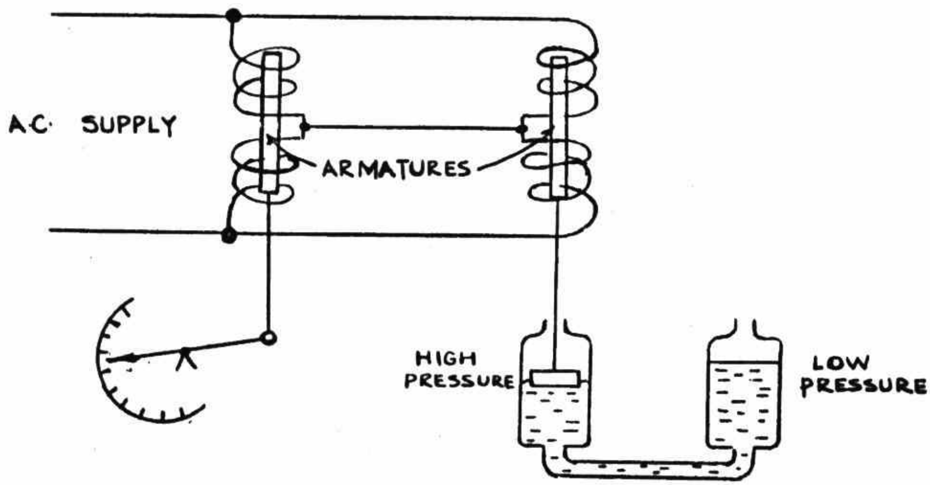
Filtration

Instrumentation and mechanical control of rapid sand filters has been used in waterworks plants for many years. The use of mechanisms became necessary because of the complex sequence of events in backwashing a filter. It was found that the sequence could be performed much better mechanically than manually. Today, it is possible to specify rapid sand filters which do not even require the full time attention of an operator. Today automatic control systems make it possible to completely supervise and operate water treatment plants from the laboratory or superintendent's office. Operating tables at each filter are no longer essential.

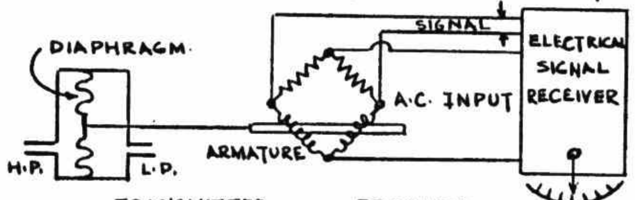
CONTINUOUS ELECTRICAL TRANSMITTERS
INDUCTANCE TYPES

FIG. 3-4

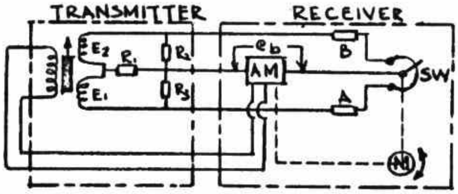
INDUCTANCE BALANCE



SOME OTHER VARIATIONS

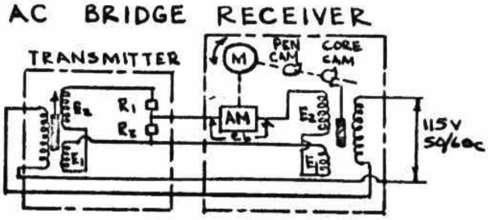


DIAPHRAGM ELEMENT TRANSMITTER



AC BRIDGE RECEIVER

SW - SLIDE WIRE
E_2, E_1 - SECONDARY VOLTAGES
$R_{1,2,3}$, A, B, CALIBRATING RESISTORS
AM - AMPLIFIER & MOTOR CONTROL
M - REVERSING MOTOR
eb - UNBALANCE VOLTAGE



VOLTAGE BALANCE RECEIVER

E_2, E_1 - SECONDARY VOLTAGES
R_1, R_2 - CALIBRATING RESISTORS
AM - AMPLIFIER & MOTOR CONTROL
e_b - UNBALANCE VOLTAGE

CONCLUSIONS

The instruments associated with the telemeter and recording and controlling of the various treatment units in the water works field are quite complicated and require skilled technicians for their calibration and repair. However, the basic principles relating to the functions of the undivided units are simple and can be understood by the operator. This understanding will aid in realizing the limitations of the equipment and in judging possible courses of problems when they occur.

OPERATION IN COLD WEATHER

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It is hoped to present a brief descriptive treatment of the experiences, methods and operating proceduces of a water system during freezing weather in an attempt to maintain the continuity of water services under adverse conditions. An analytical treatment of frost penetration, density, texture and thermal conductivity of soils, and other phenomena such as super cooling of water and formation of solid ice crystals is beyond the scope of this lecture.

PREVENTIVE PROCEDURES

It is possible to plan and construct a water system to such standards that there would be no operating problems due to freezing weather. Such a system however involve tremendous expense in original cost and in routine operation and maintenance. In this respect, each designer or operator must determine what optimum standards or procedures to follow, consistent with the expected cold weather pattern in the area, and consider the economics of deviating from this norm. These procedures are usually determined by direct experience or the experience of other successful installations under similar conditions. The system should be constructed to standards that are sufficient to protect the facilities during normal freeze plus a reasonable factor of safety below this point.

UNDERGROUND FACILITIES

General depth standards have been developed, suitable for each area. In the Toronto area water mains are normally installed with a minimum of 5 1/2' - 6' cover and house services are usually given at least 4 1/2' of cover. The main reason is for frost protection but there are other factor involved in the depth location of a water main eg. soil conditions, existence of other underground utilities, etc.

EQUIPMENT AND TOOLS

Needless to say, all work and maintenance equipment should be checked, serviced and winterized prior to the freezing season. Mobile and power equipment should be available for duty under all conditions. During extremely cold weather, it is wise to store air compressors, portable pumps, generators and other power driven equipment in a heated or otherwise protected enclosure. This ensures quick starting of motors and the availability of equipment when required.

Power and air tools should be in good working order and small hand tools and special items such as turn off or curb cock keys, wrenches etc. should be on hand in sufficient quantities to supply additional emergency crews. Extra street baricades, red lanterns or other warning devices, should be available.

MATERIALS AND SUPPLIES

Sufficient quantities of spare and repair parts should be available, including pipe, pipe repair clamps, sleeves and couplings, water service parts, meter repair parts etc.

When ice forms on the street surface after the escape of water from a broken main or service, a supply of sand should be available to be scattered on the ice.

MAIN BREAKS

Extremely cold weather usually results in a higher frequency of broken or ruptured mains. This is caused by additional stresses induced in the pipe by rapid fluctuations in the temperature of the water. The medium surrounding the pipe, gravel backfill,clay,sand,etc. becomes progressively colder and the water travelling in the main may change in temperature

quite rapidly. Stresses which are caused by lengthwise contractions of the pipe are cumulative and add to the existing stresses due to internal pressure and cause tension breaks which are characterized by being circumferential or perpendicular to the axis of the pipe. There is a slight loss of strength because pipe materials become more brittle at lower temperatures. The converse is true when there is an abrupt rise in the temperature; the breaks then caused are the result of extreme compression at the point of rupture, caused by cumulative expansion of the pipe. It is therefore evident that complete protection of the pipe from external freezing conditions will not eliminate breaks if the water flows through the pipes too rapidly and is subject to severe temperature changes.

REPAIRS TO MAINS

Repairs to broken mains must be given top priority and crews conducting this work should be supplemented when required. During emergency periods trained personnel should be concentrated on the repair of the break and minor repairs or routine duties should be assigned to others where possible.

Freezing of non-circulating mains subject to exposure can often be prevented by opening the blow-off connection at the dead end and permitting a constant flow of water during severe weather. This should be adopted as a normal operating procedure of mains suspended from bridges and culverts where adequate protection is not provided.

Where mains do freeze as a result of say shallow depth of installation, one method of thawing that has been tried is the application of an electrical current and utilizing the heat created by the electrical resistance of the pipe to thaw the main. Varying degrees of success have been achieved but there are a number of important disadvantages. The amount of current necessary to thaw sections of frozen pipe by resistance is relatively large and can be hazardous under certain conditions. The rubber rings in hydraulic couplings can be severly damaged. Iron rust and scale deposited on the inside of the pipe can be loosened in steel pipe by the action of electrolysis.

The best protection against freezing of mains and services is to install them at a reasonable depth below the normal line of frost penetration. It has been found, after a break occurs, that old mains had been installed at too shallow a depth or that street grading operations had subesquently removed some of the cover. As soon as such a condition is discovered the mains should be scheduled for lowering or replacement. Sometimes the

discovery is not made until freezing has actually occured and then it necessary to thaw and restore the frozen section under the worst possible working conditions. In such repairs, frozen fill or spoil should not be used for backfilling.

METERS AND SERVICES

Water meters are most susceptile to freezing being closer to the ground surface ie. when they are yard or curb meters located outside the house or building. In most localities, especially the Toronto area, all the new meter installations are made inside the building and are thus protected. Meters that are installed outside are normally set at a depth of 3 1/2' - 4' depending on climate conditions but these are not widely used.

HYDRANTS

Hydrants should be inspected at least once each year preferably prior to freezing weather. One of the most important checks to make is that the hydrant drains properly after closing. Where the general soil conditions are sand or sandy clay, it is generally very easy for water to drain away from the hydrant through a small hole at the bottom of the barrel. However, in more clayey soils the greater impermeability prevents good drainage and it is therefore often necessary to pump the water out of the hydrant. Hydrants known to be used during the winter usually require additional inspections. Sometimes hydrants are mistakenly thought to be frozen in extremely cold weather because the operating stem sticks or seizes in the bonnet gland packing. This seizing of the stem may be caused by the small amount of moisture or condensation sometimes present around the gland. Firemen should be advised to expect this condition occasionally. A small ring of waste or packing saturated in kerosene, placed round the operating nut or bonnet shield and ignited will thaw out the gland immediately.

CUSTOMER SERVICE

Experience has shown that if temperature conditions run true the pattern, the greatest frequency of shut-off calls occurs during the two periods of 4:30 - 8:30 pm. and 6:00 - 8:00 am. The afternoon rise in call frequency is probably because most people are at work during the day and discover the trouble upon their return. The early morning rise in call frequency is undoubtedly attributable to discovery of the trouble

when the customers arise and to the fact that the extremely low temperature encountered usually occur at about sunrise. Where possible, duty hours of personnel should be adjusted to meet these peaks.

PLANT PROBLEMS

Problems of freezing in the operation of pumping and filtration facilities are usually minor if the plant is properly designed and operated. It is not too difficult or expensive to eliminate most of the risks of freezing. On some cases there may be difficulty with anchored ice in exposed basins or tanks. Damage to baffles, weirs, or other facilities may result if the ice anchors to such appurtenances and if there is a subsequent change in the level supporting the ice. Either the ice must be kept broken up or the water level must be held nearly constant.

It is often advisable to apply heat to liquid chlorine cylinders and to gas chlorinators to maintain operating pressures. At lower temperatures, there is some loss of efficiency and reaction time of chemicals, especially alum, and hence a greater amount of suspended matter may reach the filters.

RISERS, GAUGES AND INSTRUMENTS

There are always some devices or appurtenances that may be overlooked from the standpoint of freezing protection. Among these are recording or indicating pressure gauges on outdoor installations. If electric power is available at the installation, consideration should be given to permanent installation of small resistance strip heaters in an enclosure with the gauge or measuring device. These heaters also serve to keep down moisture around precision equipment. If electric power is not available at the location, provision should be made for one or more ordinary kerosene lanterns during extremely cold weather.

Many of the newer plants today have all or most of the gauges and measuring devices located inside one control building which obviates the necessity of individual protection of instruments.

Gauge lines or pilot lines may sometimes be exposed with no reasonable or economical way to protect them. There are several types of electric heating wire that can be wrapped around the exposed pipe.

Water level-indicating floats and float switch controls should not be looated too near the wall of exposed tanks where ice may form. In small tanks it may be possible to use a probe to break away the ice on the surface of the water, if the ice interferes with the operation of floats.

Small diameter risers to elevated tanks should be jacketed and insulated. If the riser is 12" diameter or less there is a probability of solid freezing during prolonged periods of sub-freezing weather.

CONCLUSIONS

Although it may not be possible to guarantee the protection of all facilities by the procedures described, it has been found by experience that they have helped to minimize what might otherwise have proved to be crippling circumstances. These procedures have been developed over a period of years and have worked so efficiently that their continued use seems to be warranted. It should be emphasized that the most important factor in operating under emergency conditions, is the whole hearted cooperation of competent supervisors and personnel. It is to those people that full credit should be given for a job well done.

OPERATION IN EMERGENCIES

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INTRODUCTION

Emergencies which may be caused by flood, storm, fire and explosion are unpredictable. Every water works, whether operated by a municipality, public utilities commission, institution or private company, should have a plan to place into immediate action should a disaster come. The water works should aim to maintain pressure in the distribution system, to make needed repairs promptly, to proceed with emergency chlorination until all danger from contamination is passed and to keep its consumers informed throughout all stages of the disaster.

A review of the material published in the American Water Works Association Journal shows that the topic of emergency operation has been discussed by three different interest groups in the water works field. Many of the articles written are for the benefit of management and cover such subjects as emergency organization planning, communications, press and public relations, personnel training, emergency headquarters location and orivision of emergency supplies. Important planning considerations, such as the safe location of water works, alternate water supplies, standby and alternate power supplies and the location and type of control valves, are written by designers and builders of water works system. Information is also available on the actual operation of the water works during periods of emergency.

Unfortunately, floods, hurricanes and electrical and ice storms are not unknown to Ontario. All plant operators should be familiar with the following emergency operating procedures and should ne prepared to carry them out at short notice. Operation through difficulties arising from severe cold weather, obsolesence, improper design, inadequate maintenance, water hammer and war are not included.

CHLORINATION TREATMENT AT THE WATER WORKS

Flood waters entering the system from the water works should be chlorinated at such a rate to give a chlorine residual of about 2 p.p.m. after 15 minutes contact time. Personnel with chlorine testing kits should begin to fan out from the plant to determine the travel of the chlorinated water. The rate of application should then be adjusted to maintain a chlorine residual of between 0.5 and 1.0 p.p.m. in all parts of the distribution system. Any spot that does not clear up within a reasonable period of time should be flushed by opening hydrants. Bacteriological samples should also be taken to prove the effectiveness of the chlorination.

An unpalatable water drives consumers to use other waters which may be unsafe. If heavy chlorination causes objectionable tastes and odors, ammonia in the form of ammonium sulphate or anhydrous ammonia may also be added at the water works to minimize tastes due to chlorine. Concentrations of chlorine in excess of 1.p.p.m. may kill goldfish. The consumer should be educated to consider the smell and taste of chlorine as a sign of safe water rather than undesirable water.

If the distribution system becomes contaminated during the disaster or following it, the health department officials through the disaster headquarters should issue a warning that all water used for drinking and cooking purposes should be boiled until the system has been found bacteriologically safe.

SHUT DOWN PROCEDURES

If it becomes necessary to shut down the water works, all consumers should be warned in advance. The people should be asked to store water but not to fill bathtubs in order to avoid a sudden demand on the system which may dangerously deplete pressures and reduce fire flows:

(1) Well Supplies

When a flood threatens to cover a well, the unit should be run continuously to fill all storage reservoirs. The motor shaft should then be uncoupled; the bolt holding the motor frame to the bedpipe loosened; and the motor blocked high anough in the air to be out of reach of the water. The breather pipe should be plugged. Every effort should be made to keep the flood water from entering and contaminating the well. A ring levy of clay mud and sand bags will hold back five feet of water if built wide enough.

(2) Surface Supplies

As flood water reach the elevation at which the water plant's protection levies will be topped or a break may occur, the operator should begin to prepare the plant for shut down.

In all electric powered plants, the first step is the notification of the power company when the entire plant will be shut down. After emergency, portable standby lighting equipment has been put in service, all switches controlling incoming electric power should be opened and tests made after the power is turned off to make sure that no electric current will reach the plant after flooding begins. Other precautions, such as removing gasoline and oil stored below high water level, should be taken. These materials, spread over the water surface create a fire hazard and make the cleaning of equipment difficult.

At steam powered plants the fires should be extinguished far enough in advance of the actual flooding of the boiler room to permit the firebox lining to cool. This will reduce the fractured damage to fire brick when it is suddenly subjected to cold water.

All readily removable items of equipment, chemicals and supplies should be secured out of danger.

(3) Distribution System

In order to cope with distribution system emergencies, special service vehicles should be available and equipped with two-way radios, hand or power operated valve keys, auxiliary generators for emergency lighting, pressure gauges, pipe and valve locaters and chlorination equipment.

Probably the most important item is a complete set of maps and notes showing reservoirs lay-outs, feeder mains, distribution mains, stream crossings and control valves at street intersections.

The loss of bridges and wash-outs may necessitate the shutdown of larger feeder mains. The shutting down of a large main is not a casual operation but one calling for speed, training, and previously planned procedure. There must be some means of knowing when a break occurs and on what main. This information should be transmitted to the repair crews as soon as possible. The man in charge of the crew should have a plan showing what valves are to be operated to effect the desired results. It should be pointed out that it may take three to four men up to thirty minutes to close manually operated 12-inch or 16-inch gate valves.

A flooded distribution system should not be polluted if the pressure has not been off in the system.

DISINFECTION OF MAINS

The principle causes of contamination are:

1. Main breaks;
2. Back-flow through faulty plumbing;
3. Cross-connections;
4. Reduced pressure within the system.

There may be a tendency to overlook disinfection when the need for resoring services is grave. Regardless of the urgency, disinfection must be carried out. For the disinfection of contaminated mains the following procedure should be used:

1. Shut off main;
2. Repair main as soon as possible;
3. Thoroughly flush main of all sediment;
4. Inject 50 p.p.m. chlorine and rest for 4 to 24 hours;
5. Flush main thoroughly;
6. Enter premises and instruct the occupants to flush the system by opening every faucet for fifteen minutes.

It is important to thoroughly cleanse and flush the mains before treatment is commenced. Disinfection of grossly contaminated mains may be faciliated by first sludging the system with a heavy dose of 200 to 250 p.p.m. and following this by water containing 50 p.p.m. for 4 to 24 hours. The chlorine may be applied by means of mobile chlorinating units or by using hypochlorite powder solution. Some operators prefer to use portable chlorination equipment rather than relying on the placing of hypochlorite in each length of pipe. Other operators prefer to keep all chlorination equipment at the water works and provide for disinfection of mains with the least amount of equipment.

The system can also be disinfected by raising the pH to 10.5 with common hydrated lime. When flushing the system it is necessary to see that the pH is 10.5 at all ends of the system.

EMERGENCY CHLORINATION ,ETHODS:

A complete description of a temporary chlorine cylinder filling station from tank to cars is given in the September, 1954 issue of the AWWA Journal. The article written by Mr. B.L. Shera also describes how calcium hypochlorite solution can be made from lime and liquid chlorine.

The presence of chlorine is usually detected by means of orthotolidine. Chlorine residuals up to 10 p.p.m. will give a yellow colour with orthotolidine. Residuals between 15 to 20 p.p.m. give a bright red colour, and residuals of about 50 p.p.m. give a brown precipitate with orthotolidine.

1. Direct Gas Feeding

A dry feed gas chlorinator consists essentially of a reducing valve and a rate of flow indicator. Fluctuations in gas pressure due to temperature variations of the liquid chlorine are minimized by enclosing the cylinder within a vertical nest of cells through which pass tap water.

If a dry feed gas chlorinator is used to apply chlorine to an open flume, the diffuser on the end of the supply line should be submerged at least four feet and preferrably six feet.

A chlorine cylinder without equipment may be used for direct feed during an emergency, controlling the rate by counting the bubbles per minute through a water trap. Low sensitivity of the cylinder valve limits the adjustment to about one-half pount per hour per cylinder.

A detailed description of one procedure using chlorine cylinders follows: Following the repair of the main, a section of pipe is left out so that a high velocity wash can be obtained to remove small stones and other debris. Two taps are made above the break and two chlorine diffusers are inserted. Chlorine cylinders are then connected to each diffuser. Chlorine is applied to the water used to wash out the line. Upon replacing the length of pipe which is removed for cleaning purposes a blow-our valve or hydrant is opened at the end of the contaminated area. The pressure in the line should be kept under thirty pounds to permit direct feeding from the cylinders. Once a

blood red residual is obtained, the blow-off or hydrant is closed and the line is allowed to stand for four to twelve hours. Then the water is blown off. The blow-off is closed when a residual of about 0.2 to 0.3 p.p.m. is obtained. This system is useful only when the pressure is considerably less then that of the cylinders.

2. Hypochlorinators

Reciporcating pump-type hypochlorinators are applicable to water supplies ranging from 100 to 100,000 gallons per day. Injection pressures may reach 100 p.s.i. Pumps are usually of the diaphragm type pulsating in a rubber, glass or plastic chamber.

3. Gravity Hypochlorite Solution Feeders

Chlorine solution can be fed into an open channel through an orifice tank having a float valve to maintain a constant solution level. The orifice tank has an orifice insert in the valved outlet union. The float is connected to a valve on the discharge line from a stock tank elevated above the orifice tank. Uniformly of feed is obtained by the constant level orifice tank which may be a toilet flush tank. The orifice may be made by inserting a corrosion resisting disc. having a hole and reemed to the proper size of the union.

For maximum simplicity, the hypochlorite solution can be fed with sufficient uniformity without constant level control provided the tank is above the orifice discharge. If the variation of the operating level in the tank is restricted to 2 feet, this elevation provides uniform dosage within 5 per cent. The orifice is merely a perforated cap into which a series of liners having various diameter openings may be inserted to vary the feed rate. Control may also be had by means of a stop valve.

REHABILITATION

All flood water and silt should be removed from reservoirs, pumpwells and basements. The affected areas should then be disinfected with a strong chlorine solution (250 to 300 p.p.m.). The floors and side walls should be scrubbed down thoroughly. All water used for scrubbing should then be removed.

Sand filters should be thoroughly washed and sterilized with a strong chlorine solution. When the filters and reservoirs

are cleaned and placed in operation, chlorine residuals at the plant of 2 to 3 p.p.m. should be maintained until bacteriological tests show that normal chlorination treatment can be safely resumed.

All flooded or damp motors and other electrical equipment should be thoroughly dried and inspected before re-use. Where necessary, new equipment should be installed.

Flooded motors are reconditioned by heating. This may be done by immersing the motor in hot parafin, placing it in an infra-red cabinet or using other lamp arrangements. After the East Chicago pumping station failure in January, 1949, the flooded motors were first subjected to a current at low amperage and voltage, thus utilizing internal heat of the motors. Then, special lamps were used for the final drying.

New motors may sometimes be dried with a blow torch if handled by an experienced electrician for care is needed to avoid burning of the installation.

QUESTION

Part A

What chlorine residual range should be maintained in all parts of the distribution system when flood water is being pumped from the water works ?

Answer: 0.5 to 1.0 p.p.m. by the orthotolidine test.

Part B

What minimum chlorine dose is required to disinfect contaminated mains when a detention time of 4 to 24 hours is used ?

Answer: 50 p.p.m. by the orthotolidine test.